COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

# GRADUATE CATALOG

# 2020-2021

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# Colorado School of Mines

## COVID19 RESPONSE (https://www.mines.edu/coronavirus/)

For addendums to the current catalog that were not available at the time of production, click here: Mines.edu/Registrar/program-changes (https://www.mines.edu/registrar/program-changes/)

## Mission, Vision and Values

Colorado statutes define the role of the Colorado School of Mines as: *The Colorado School of Mines shall be a specialized baccalaureate and graduate research institution with high admission standards. The Colorado School of Mines shall have a unique mission in energy, mineral, and materials science and engineering and associated engineering and science fields. The school shall be the primary institution of higher education offering energy, mineral and materials science and mineral engineering degrees at both the graduate and undergraduate levels. (Colorado revised Statutes: Section 23-41-105).*

The Board of Trustees of the Colorado School of Mines has elaborated on this statutory role with the following statement of the School's mission, vision and values.

## Mission

***Education and research in engineering and science to solve the world's challenges related to the earth, energy and the environment***

- Colorado School of Mines educates students and creates knowledge to address the needs and aspirations of the world's growing population.
- Mines embraces engineering, the sciences, and associated fields related to the discovery and recovery of the Earth's resources, the conversion of resources to materials and energy, development of advanced processes and products, fundamental knowledge and technologies that support the physical and biological sciences, and the economic, social and environmental systems necessary for a sustainable global society.
- Mines empowers, and holds accountable, its faculty, students, and staff to achieve excellence in its academic programs, its research, and in its application of knowledge for the development of technology.

## Vision

***Mines will be the premier institution, based on the impact of its graduates and research programs, in engineering and science relating to the earth, energy and the environment***

- Colorado School of Mines is a world-renowned institution that continually enhances its leadership in educational and research programs that serve constituencies throughout Colorado, the nation, and the world.
- Mines is widely acclaimed as an educational institution focused on stewardship of the earth, development of materials, overcoming the earth's energy challenges, and fostering environmentally sound and sustainable solutions.

## Values

***A student-centered institution focused on education that promotes collaboration, integrity, perseverance, creativity, life-long learning, and a responsibility for developing a better world***

- The Mines student graduates with a strong sense of integrity, intellectual curiosity, demonstrated ability to get a job done in collaborative environments, passion to achieve goals, and an enhanced sense of responsibility to promote positive change in the world.
- Mines is committed to providing a quality experience for students, faculty, and staff through student programs, excellence in pedagogy and research, and an engaged and supportive campus community.
- Mines actively promotes ethical and responsible behaviors as a part of all aspects of campus life.

*(Colorado School of Mines Board of Trustees, 2013)*

# Graduate

To Mines Graduate Students:
This Catalog is for your use as a source of continuing reference. Please save it.

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Colorado School of Mines,
Golden, CO 80401

Address correspondence:

Office of Graduate Studies
Colorado School of Mines
Golden, CO 80401-1887
Main Telephone: 303-273-3247
Toll Free: 800-446-9488
https://www.mines.edu/graduate-studies/contact/

# Academic Calendar

## Fall Semester 2020 through Summer Semester 2021 **(**https://www.mines.edu/registrar/**)**

# General Information

Graduate Student Profile

Mines graduates identify and address grand challenges of the 21st century using innovative applications of sound scientific and engineering principles. They act as contributors and leaders of multidisciplinary teams to deliver impactful results for the betterment of society.

Mines graduates are skilled in the acquisition, interpretation, and analysis of data as well as communication of information to diverse audiences. They exemplify ethical behavior including academic and professional integrity, respect for diversity of all types, and recognition of the value of living and working in an interdependent world. Mines graduates are global citizens who possess exceptional adaptability and grit in the face of challenges as stewards of the **Earth, Energy, and Environment.**

## Institutional Values and Principles

## Graduate Education

The Colorado School of Mines is dedicated to serving the people of Colorado, the nation and the global community by providing high quality educational and research experiences to students in science, engineering and related areas that support the institutional mission. Recognizing the importance of responsible stewardship of the Earth, Energy, and Environment, Mines places particular emphasis on those fields related to the discovery, production, and utilization of resources needed to improve the quality of life of the world's inhabitants and to sustain the earth system upon which all life and development depend. To this end, Mines is devoted to creating a learning community that provides students with perspectives informed by the humanities and social sciences, perspectives that also enhance students' understanding of themselves and their role in contemporary society. Mines, therefore, seeks to instill in all graduate students a broad class of developmental and educational attributes that are guided by a set of institutionally vetted educational objectives and student learning outcomes. For doctoral and master’s degree programs, these are summarized below.

### Doctoral Programs

*Institutional Educational Objectives:*

1. PhD graduates will advance the state of the art of their discipline (integrating existing knowledge and creating new knowledge) by conducting independent research that addresses relevant disciplinary issues and by disseminating their research results to appropriate target audiences.
2. PhD graduates will be scholars and international leaders who exhibit the highest standards of integrity.
3. PhD graduates will advance in their professions and assume leadership positions in industry, government, and academia.

*Institutional Student Outcomes:*

1. Demonstration of exemplary disciplinary expertise.
2. Demonstration of a set of skills and attitudes usually associated with our understanding of what it is to be an academic scholar (e.g., intellectual curiosity, intellectual integrity, ability to think critically and argue persuasively, the exercise of intellectual independence, a passion for life-long learning, etc.).
3. Demonstration of a set of professional skills (e.g., oral and written communication, time-management, project planning, teaching, teamwork and team leadership, cross-cultural and diversity awareness, etc.) necessary to succeed in a student's chosen career path.

### Master's Programs

The Colorado School of Mines offers a wide variety of Master’s-level degree programs that include thesis and non-thesis Master of Science programs, Master of Engineering programs and Professional Master's programs. While the objectives and outcomes provided below document expectations of all Master’s-level programs, it is expected that given the diversity of program types, different programs will emphasize some objectives and outcomes more than others.

*Institutional Educational Objectives:*

1. Master's graduates will contribute to the advancement of their chosen fields through adopting, applying and evaluating state-of-the-art practices.
2. Master's graduates will be viewed within their organizations as technologically advanced and abreast of the latest scholarship.
3. Master's graduates will exhibit the highest standards of integrity in applying scholarship.
4. Master's graduates will advance in their professions.

*Institutional Student Outcomes:*

1. Graduates will demonstrate exemplary disciplinary expertise.
2. Graduates will demonstrate the ability to conduct direct research, the ability to assimilate and assess scholarship, and the ability to apply scholarship in new, creative and productive ways.
3. Graduates will demonstrate professional skills (e.g., oral and written communication, time-management, project planning, teamwork and team leadership, cross-cultural and diversity awareness, ethics, etc.) necessary to succeed in a student's chosen career path.

### Research

The creation and dissemination of new knowledge are the primary responsibilities of all members of the university community and fundamental to the educational and societal missions of the institution. Public institutions have an additional responsibility to use that knowledge to contribute to the economic growth and public welfare of the society from which they receive their charter and support. As a public institution of higher education, a fundamental responsibility of Mines is to provide an environment that enables contribution to the public good by encouraging creative research and ensuring the free exchange of ideas, information, and results. To this end, the institution acknowledges the following responsibilities:

- To ensure that these activities are conducted in an environment of minimum influence and bias, it is essential that Mines protect the academic freedom of all members of its community.
- To provide the mechanisms for creation and dissemination of knowledge, the institution recognizes that access to information and information technology (e.g., library, computing and internet resources) are part of the basic infrastructure support to which every member of the community is entitled.
- To promote the utilization and application of knowledge, it is incumbent upon Mines to define and protect the intellectual-property

rights and responsibilities of faculty members, students, as well as the institution.

- To ensure integration of research activities into its basic educational mission, its research policies and practices conform to the state non-competition law requiring all research projects have an educational component through the involvement of students and/or post-doctoral fellows.

## Intellectual Property

The creation and dissemination of knowledge are the primary responsibilities of all members of the university community. As an institution of higher education, a fundamental mission of Mines is to provide an environment that motivates the faculty and promotes the creation, dissemination, and application of knowledge through the timely and free exchange of ideas, information, and research results for the public good. To ensure that these activities are conducted in an environment of minimum influence and bias, so as to benefit society and the people of Colorado, it is essential that Mines protect the academic freedom of all members of its community. It is incumbent upon Mines to help promote the utilization and application of knowledge by defining and protecting the rights and responsibilities of faculty members, students and the institution, with respect to intellectual property which may be created while an individual is employed as a faculty member or enrolled as a student.

## History of Colorado School of Mines

In 1865, only six years after gold and silver were discovered in the Colorado Territory, the fledgling mining industry was in trouble. The nuggets had been picked out of streams and the rich veins had been worked, and new methods of exploration, mining, and recovery were needed.

Early pioneers like W.A.H. Loveland, E.L. Berthoud, Arthur Lakes, George West and Episcopal Bishop George M. Randall proposed a school of mines. In 1874, the Territorial Legislature appropriated $5,000 and commissioned Loveland and a Board of Trustees to found the Territorial School of Mines in or near Golden. Governor Routt signed the Bill on February 9, 1874, and when Colorado became a state in 1876, the Colorado School of Mines was constitutionally established. The first diploma was awarded in 1883.

As Mines grew, its mission expanded from the rather narrow initial focus on nonfuel minerals to programs in petroleum production and refining as well. Recently, it has added programs in materials science and engineering, energy and environmental engineering, and a broad range of other engineering and applied science disciplines. Mines sees its mission as education and research in engineering and applied science with a special focus on the earth science disciplines in the context of responsible stewardship of the earth and its resources.

Mines long has had an international reputation. Students have come from nearly every nation, and alumni can be found in every corner of the globe.

## Location

Golden, Colorado, has always been the home of Mines. Located in the foothills of the Rocky Mountains 20 minutes west of Denver, this community of 15,000 also serves as home to the Coors Brewing Company, the National Renewable Energy Laboratory, and a major U.S. Geological Survey facility that also contains the National Earthquake Center. The seat of government for Jefferson County, Golden once served as the territorial capital of Colorado. Skiing is an hour away to the west.

## Administration

By State statute, the school is managed by a seven-member board of trustees appointed by the governor, and the student and faculty bodies elect one nonvoting board member each. The school is supported financially by student tuition and fees and by the State through annual appropriations. These funds are augmented by government and privately sponsored research, private gift support from alumni, corporations, foundations and other friends.

## Colorado School of Mines Non-Discrimination Statement

In compliance with federal law, including the provisions of Titles VI and VII of the Civil Rights Act of 1964, Title IX of the Education Amendment of 1972, Sections 503 and 504 of the Rehabilitation Act of 1973, the Americans with Disabilities Act (ADA) of 1990, the ADA Amendments Act of 2008, Executive Order 11246, the Uniformed Services Employment and Reemployment Rights Act, as amended, the Genetic Information Nondiscrimination Act of 2008, and Board of Trustees Policy 10.6, the Colorado School of Mines does not discriminate against individuals on the basis of age, sex, sexual orientation, gender identity, gender expression, race, religion, ethnicity, national origin, disability, military service, or genetic information in its administration of educational policies, programs, or activities, admissions policies, scholarship and loan programs, athletic or other school-administered programs, or employment.

Inquiries, concerns, or complaints should be directed by subject content as follows:

EO and Discrimination contact:
Human Resources Office
1500 Illinois Street
Golden, Colorado 80401

The ADA Coordinator and the Section 504 Coordinator for employment:
Human Resources Office
1500 Illinois Street
Golden, Colorado 80401

The ADA Coordinator and the Section 504 Coordinator for students and academic educational programs:
Marla Draper, Director of Disability Support Services
Ben H. Parker Student Center, Suite E110
Golden, Colorado 80401
(Telephone: 303.273.3297)

The Title IX Coordinator:
Katie Schmalzel, Director of Title IX Programs
Golden, Colorado 80401
(Telephone: 303.273.3206)
(email: kschmalz@mines.edu)

The ADA Facilities Access Coordinator:
Gary Bowersock, Director of Facilities Management
1318 Maple Street
Golden, Colorado 80401
(Telephone: 303.273.3330)

# The Graduate School

## 2020-2021

https://www.mines.edu/graduate-studies/

## Unique Programs

Because of its special focus, Colorado School of Mines has unique programs in many fields. For example, Mines is the only institution in the world that offers doctoral programs in all five of the major earth science disciplines: Geology and Geological Engineering, Geophysics, Geochemistry, Mining Engineering, and Petroleum Engineering. It also has one of the few Metallurgical and Materials Engineering programs in the country that still focuses on the complete materials cycle from mineral processing to finished advanced materials.

In addition to the traditional programs defining the institutional focus, Mines is pioneering both undergraduate and graduate interdisciplinary programs. Mines understands that solutions to the complex problems involving global processes and quality of life issues require cooperation among scientists, engineers, economists, and the humanities.

Mines offers interdisciplinary graduate programs in areas such as Advanced Energy Systems, Advanced Manufacturing, Geochemistry, GIS & GeoInformatics, Humanitarian Engineering & Science, Hydrologic Science & Engineering, Materials Science, Nuclear Science & Engineering, Operations Research with Engineering, Quantitative Biosciences & Engineering, Space Resources, and Underground Construction & Tunneling Engineering. These programs make interdisciplinary connections between traditional fields of engineering, physical science and social science, emphasizing a broad exposure to fundamental principles while cross-linking information from traditional disciplines to create the insight needed for breakthroughs in the solution of modern problems. Additional interdisciplinary degree programs may be created by Mines' faculty as need arises.

Lastly, Mines offers a variety of non-thesis Professional Master's degrees to meet the career needs of working professionals in Mines' focus areas.

## Graduate Degrees Offered

Mines offers graduate certificate, professional master's, master of science (MS), master of engineering (ME) and doctor of philosophy (PhD) degrees in the disciplines listed in the chart.

In addition to master's and PhD degrees, departments and divisions can also offer graduate and post-baccalaureate certificates. Graduate and post-baccalaureate certificates are designed to have selective focus, short time to completion, and consist of course work only.

## Accreditation

Mines is accredited through the doctoral degree by the following:
The Higher Learning Commission (HLC) of the North Central Association
230 South LaSalle Street, Suite 7-500
Chicago, Illinois 60604-1413
telephone (312) 263-0456

The Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology
111 Market Place, Suite 1050
Baltimore, MD 21202-4012
telephone (410) 347-7700

The Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology accredits undergraduate degree programs in chemical engineering, engineering, engineering physics, geological engineering, geophysical engineering, metallurgical and materials engineering, mining engineering and petroleum engineering. The American Chemical Society has approved the degree program in the Department of Chemistry and Geochemistry.

| Degree Programs | Prof. | M.S. | M.E. | Ph.D. | Cert. |
|---|---|---|---|---|---|
| Advanced Energy Systems | | x | | x | |
| Advanced Manufacturing | | x | | | x |
| Antennas & Radar Technology | | | | | x |
| Applied Chemistry | | | | x | |
| Applied Mathematics and Statistics | | x | | x | |
| Applied Physics | | x | | | |
| Business Analytics | | | | | x |
| Chemical Engineering | | x | | x | |
| Chemistry | | x | | | |
| Civil & Environmental Engineering | | x | | x | |
| Computer Science | | x | | x | x |
| CyberSecurity for Cyber Physical Systems | | | | | x |
| Data Science | | x | | | |
| Data Science - Computer Science | | | | | x |
| Data Science - Foundations | | | | | x |
| Data Science for Signals and Systems | | | | | x |
| Earth Resource Data Science | | | | | x |
| Earth Resources Development Engineering | | x | | x | |
| Economic Geology | | | | | x |
| Electrical Engineering | | x | | x | |
| Engineering & Technology Management | | x | | | |
| Entrepreneurship | | | | | x |
| Environmental Geochemistry | x | | | | |
| Environmental Engineering Science | | x | | x | |
| Environmental Modeling | | | | | x |
| Exploration Methods | | | | | x |
| Finite Element Analysis | | | | | x |
| Geochemistry | | x | | x | |
| Geological Engineering | | x | x | x | |
| Geology | | x | | x | |
| Geophysical Engineering | | x | | x | |
| Geophysics | | x | | x | |
| GIS & GeoInformatics | | x | | | |
| GIS & Geoinformatics: Geospatial Information Technology | | | | | x |
| GIS & Geoinformatics: GIS for Environmental Studies | | | | | x |
| GIS & Geoinformatics: GIS for Geohazards Evaluation | | | | | x |

| | | | | | |
|---|---|---|---|---|---|
| GIS & Geoinformatics: GIS for Natural Resources Assessment | | | | | x |
| Humanitarian Engineering & Science | | x | | | x |
| Hydrology | | x | | x | |
| Materials Science | | x | | x | |
| Mechanical Engineering | | x | | x | |
| Metallurgical & Materials Engineering | | x | x | x | |
| Mineral & Energy Economics | | x | | x | |
| Mineral Exploration | x | | | | |
| Mining Engineering | | x | | x | |
| Mining Engineering and Management | x | | | | |
| Natural Resources and Energy Policy | | x | | | x |
| Nuclear Engineering | | x | x | x | |
| Operations Research with Engineering | | x | | x | |
| Petroleum Engineering | | x | x | x | |
| Petroleum Geophysics | | | | | x |
| Petroleum Reservoir Systems | x | | | | |
| Physics | | | | x | |
| Product Management | | | | | x |
| Quantitative Biosciences and Engineering | | x | | x | |
| Quantum Engineering | | x | | x | x |
| Resource Commodity Analytics | | | | | x |
| RF and Microwave Engineering | | | | | x |
| Robotics | | x | | x | x |
| Smart Grid, Power Electronics & Electrical Power Systems | | x | | | x |
| Smart Manufacturing | | | | | x |
| Space Resources | | x | | x | x |
| Underground Construction and Tunnel Engineering | | x | | x | x |

# Admission to the Graduate School

## Admission Requirements

The Graduate School of Colorado School of Mines is open to bachelor level and above graduates from recognized colleges or universities. Admission to all graduate programs is competitive, based on an evaluation of prior academic performance, test scores, and references. The academic background of each applicant is evaluated according to the requirements of each department outlined later in this section of the Catalog.

To earn a post-baccalaureate certificate, a graduate certificate, or a graduate degree, students must have completed an appropriate undergraduate degree program. Colorado School of Mines undergraduate students in the Combined Degree Program may, however, work toward completion of graduate degree requirements prior to completing undergraduate degree requirements. See the Combined Undergraduate/Graduate Degree section of the Graduate Catalog for details of this program.

## Categories of Admission

There are four categories of admission to graduate studies at Colorado School of Mines: regular, provisional, graduate non-degree, and foreign exchange.

## Regular Degree Students

Applicants who meet all the necessary qualifications as determined by the program to which they have applied are admitted as regular graduate students.

## Provisional Degree Students

Applicants who are not qualified to enter the regular degree program directly may be admitted as provisional degree students for a trial period not longer than 12 months. During this period students must demonstrate their ability to work for an advanced degree as specified by the admitting degree program. After the first semester, the student may request that the department review his or her progress and make a decision concerning full degree status. With department approval, the credits earned under the provisional status can be applied towards the advanced degree.

## Non-degree Students

Practicing professionals may wish to update their professional knowledge or broaden their areas of competence without committing themselves to a degree program. They may enroll for regular courses as non-degree students. Inquiries and applications should be made to the following:

Office of Admissions
grad-dmissions@mines.edu (grad-app@mines.edu)
Phone: 303-273-3247

A person admitted as a non-degree student who subsequently decides to pursue a regular degree program must apply and gain admission to the Graduate School.

- All graduate-level credits earned as a non-degree graduate student may be used towards the regular graduate degree program if the credits are not prerequisites or deficiencies and the student's graduate committee and department head approve. Graduate non-degree credits count towards the student’s graduate cumulative G.P.A. and could impact student’s academic standing as a degree seeking graduate student.
- Graduate credits earned as a non-degree undergraduate student may be transferred into the regular graduate degree program if the credits are 400 level or higher (graduate students are limited to 9 credits of 400 level coursework), the credits do not exceed the transfer limits, the transfer credits must not have been used as credit toward a Bachelor's degree (students will be required to obtain proof from the bachelor’s degree institution), the transfer credits are not prerequisites or deficiency credits and the student’s graduate committee and department head approve. Graduate credits taken while an undergraduate non-degree seeking student count towards the students undergraduate G.P.A.

## Foreign Exchange Students

Graduate level students living outside of the U.S. may wish to take courses at Colorado School of Mines as exchange students. They may enroll for regular courses as foreign exchange students. Inquiries and applications should be made to:

Mines International Office
Golden, CO 80401-0028
Phone: 303-384-2121

A person admitted as a foreign exchange student who subsequently decides to pursue a regular degree program must apply and gain admission to the Graduate School.

- All graduate-level credits earned as a graduate foreign exchange student may be used towards the regular graduate degree if the credits are not prerequisites or deficiencies and the student’s graduate committee and department head approve. Graduate exchange credits count towards the student’s cumulative GPA and could impact academic standing as a degree seeking student.
- Graduate credits earned as an exchange undergraduate student may be transferred into the regular graduate degree program if the credits are 400 level or higher (graduate students are limited to 9 credits of 400 level coursework), the credits do not exceed the transfer limits, the transfer credits were not used toward a bachelor's degree (students will be required to obtain proof from the bachelor degree institution), transfer credits are not prerequisites or deficiency credits and the student's graduate committee and department head approve.

## Combined Undergraduate/Graduate Programs

Several degree programs offer Mines undergraduate students the opportunity to begin work on a Graduate Degree while completing the requirements of their Bachelor Degree. These programs can give students a head start on graduate education. An overview of these combined programs and description of the admission process and requirements are found in the Graduate Degrees and Requirements (p. 37) section of this Catalog.

Admission into a Combined Undergraduate/Graduate degree program is available only to current Mines undergraduate students. Mines alumni are not eligible for Combined degree program enrollment.

Combined students whose graduate degree programs allow double counting of credits, may only double count if the student has uninterrupted registration from the undergraduate degree to the graduate degree. If a student takes a semester off, or more, between degrees (summer excluded), the student is no longer eligible to double count credits.

# Admission Procedure

## Applying for Admission

Both US resident and international students may apply electronically for admission. The graduate admissions web address is: https://www.mines.edu/graduate-admissions/

To apply follow the procedure outlined below.

1. Application: Go to the online application form at https://www.mines.edu/graduate-admissions/apply (https://www.mines.edu/graduate-admissions/apply/). Students wishing to apply for graduate school should submit completed applications by the following dates:
   **for Fall admission***
   December 15 - Priority consideration for financial support
   March 1 - International student deadline
   July 1 - Domestic student deadline
   **for Spring admission***
   October 1
   * Some programs have different application deadlines. Please refer to https://www.mines.edu/graduate-admissions/deadlines/ for current deadline information for specific programs. Students wishing to submit applications beyond the final deadline should contact the appropriate academic department/program.
2. Transcripts: The Office of Admissions recommends uploading electronic copies of transcripts ( .pdf format) in the Applicant Portal from each school previously attended. Electronic copies of transcripts can also be sent, via email, to grad-admissions@mines.edu (grad.credentials@mines.edu). International students' transcripts must be in English or have an official English translation attached. Transcripts are not considered official unless they are sent directly by the institution attended and are complete, with no courses in progress.
   a. All new students who have taken courses during college outside of the U.S. must submit their official college transcripts in the original language as well as a certified English translation and credential evaluation and designate Mines as a copy recipient of your evaluation. The preferred translation agencies are Educational Credential Evaluators, (ECE) or World Education Services (WES). Other National Association of Credential Evaluation Services (NACES) will be considered on a case-by-case basis.
3. Letters of Recommendation: Three (3) letters of recommendation are required for most programs. Individuals who know your personal qualities and scholastic or professional abilities can use the online application system to submit letters of recommendation on your behalf. Letters can also be mailed or emailed directly to the Office of Admissions by the recommenders.
4. Graduate Record Examination (GRE): Most departments require the General test of the Graduate Record Examination for applicants seeking admission to their programs. Refer to the section Graduate Degree Programs and Courses by Department or the individual degree program website to find out if you must take the GRE examination. For information about the test, write to the following:
   GRE-ETS
   PO Box 6000
   Princeton, NJ 08541- 6000
   (Telephone 609-771-7670)
   or visit online at www.gre.org (http://www.gre.org)
5. English Language Requirements: Student applicants whose native language is not English (see list of approved exemption countries within the application) must prove proficiency. The requirement applies to students currently studying in the U.S. and for students outside the country. Tests must have been taken within the past two years to be accepted. Applications that do not have valid scores are considered incomplete and will not be released to the department for review. Language examination results must be sent to the Office of Admissions as part of the admission process. The institution has minimum English proficiency requirements - learn more at: https://www.mines.edu/graduate-admissions/international-applicants/. English proficiency may be proven by achieving one of the following:
   a. A TOEFL (Test of English as a Foreign Language) minimum total score of 79 on the internet Based TOEFL (iBT). Minimum subject scores are as follows:
      i. Reading 20; Writing 17; Listening 21; Speaking 21.
   b. An IELTS (International English Language Testing System) Score of 6.5, with no band below a 6.0.
   c. Pearson Test of English/PTE Academic Minimum overall score of 53 with no communicative skills score below 50.
   d. Completion of a university degree program in an English speaking country within the last two (2) years.
   e. Independent evaluation and approval by the admission-granting department.
6. Additional instructions for admission to graduate school specific to individual degree programs are contained in the application for admission.

## RESEARCH OR TEACHING ASSISTANTSHIP

To be considered for a Research or Teaching Assistantship, select 'Yes' for that question under the Educational Information section of the online graduate application.

## Application Review Process

After all application materials are received by the Office of Admissions, the application is complete and is released to the desired degree program for review. The review is conducted according to the process developed and approved by the faculty of that degree program.
The degree program transmits its decision back to the Office of Admissions, which then releases the official decision letter and notifies the applicant. All admission decisions are final, with one exception.
If your admission to the Colorado School of Mines is denied based on information you provided regarding your criminal history, pending criminal charges, or disciplinary history at another academic institution, you have the right to an appeal. Appeals must be in writing and should be submitted to the Associate Provost for Enrollment Management at admissions@mines.edu within 14 days of receipt of the admissions decisions. Appeals should include all relevant information you would like the Associate Provost to consider. You will be notified of the outcome of your appeal within 14 days of receipt.

## Health Record and Additional Steps

When students first enroll at Mines, they must complete the student health record form which is sent to them when they are accepted for enrollment. Students must submit the student health record, including health history, medical examination, and record of immunization, in order to complete registration.

Questions can be addressed to the following:
The Coulter Student Health Center
1770 Elm Street
Golden, CO 80401-1869

The Health Center can be reached by telephone 303-273-3381 or by email at shc@mines.edu.

## Veterans

Colorado School of Mines is approved by the Colorado State Approving Agency for Veteran Benefits under chapters 30, 31, 32, 33, 35, 1606, and 1607. Undergraduate students must register for and maintain 12.0 credit hours, and graduate students must register for and maintain 9.0 credit hours of graduate work in any semester to be certified as a full-time student for full-time benefits. Any hours taken under the full-time category will decrease the benefits to 3/4 time, 1/2 time, or tuition payment only.

All changes in hours, program, addresses, marital status, or dependents are to be reported to the Veterans Certifying Officer as soon as possible so that overpayment or underpayment may be avoided. Veterans must see the Veterans Certifying Officer each semester to be certified for any benefits for which they may be eligible. In order for veterans to continue to receive benefits, they must make satisfactory progress as defined by Colorado School of Mines.

An honorably or generally discharged military veteran providing a copy of his/her DD214 is awarded two credit hours to meet the physical education undergraduate degree requirement at Mines. Additionally, veterans may request substitution of a technical elective for the institution's core EPICS course requirement in all undergraduate degree programs.

For more information, please visit the Veterans Services (https://www.mines.edu/veterans/) webpage.

# Student Life at Mines

Please note, if you are an online student, please visit: Mines Online (https://online.mines.edu/) for additional information on services and support.

## Housing (https://www.mines.edu/residence-life/mines-park/)

Graduate students may choose to reside in campus-owned apartment housing areas on a space-available basis. The Mines Park apartment complex is located west of the 6th Avenue and 19th Street intersection on 55 acres owned by Mines. The complex houses upperclass undergraduate students, graduate students, and families. Residents must be full-time students.

Units are complete with refrigerators, stoves, dishwashers, streaming television services, and wired/wireless internet connections. There are two community centers which contain the laundry facilities, recreational and study space, and meeting rooms. For more information or to apply for apartment housing, go to the Apartment Housing website (https://www.mines.edu/residence-life/mines-park/).

For all Housing & Dining rates, go to Room and Board Rates (https://www.mines.edu/residence-life/rates/).

## Facilities

### Student Center

The Ben H. Parker Student Center contains the offices for the Vice President of Student Life, Dean of Students, Student Activities, Involvement and Leadership, Student Government (USG & GSG), Financial Aid, Bursar and Cashier, Disability Support Services, CARE Office, Career Center, Registrar, Campus Events, Blaster Card Office and student organizations. The Student Center also contains The Periodic Table food court, bookstore, student lounges, meeting rooms, and banquet facilities.

### Student Recreation Center

Completed in May 2007, the 108,000 square foot Student Recreation Center, located at the corner of 16th and Maple Streets in the heart of campus, provides a wide array of facilities and programs designed to meet student's recreational and leisure needs while providing for a healthy lifestyle. The Center contains a state-of-the-art climbing wall, an eight-lane, 25 meter swimming and diving pool, a cardiovascular and weight room, two multi-purpose rooms designed and equipped for aerobics, dance, martial arts programs and other similar activities, a competition gymnasium containing three full-size basketball courts as well as seating for 2500 people, a separate recreation gymnasium designed specifically for a wide variety of recreational programs, extensive locker room and shower facilities, and a large lounge intended for relaxing, playing games or watching television. In addition to housing the Outdoor Recreation Program as well as the Intramurals and Club Sports Programs, the Center serves as the competition venue for the Intercollegiate Men and Women's Basketball Programs, the Intercollegiate Volleyball Program and the Men and Women's Intercollegiate Swimming and Diving Program.

### W. Lloyd Wright Student Wellness Center

The W. Lloyd Wright Student Wellness Center, 1770 Elm Street, houses several health and wellness programs for Mines students: the Coulter Student Health Center, the Student Health Insurance Plan, the Counseling Center, the Dental Clinic, and Student Wellness Promotions. The Wellness Center is open from 8:00 am to 5:00 pm, Monday through Friday during the fall and spring semesters. Check the website for summer and holiday hours. The Wellness Center follows the weather delay and closure schedule set for the campus.

**Coulter Student Health Center:** Services are provided to all students who have paid the student health services fee. The Coulter Student Health Center (phone 303-273-3381, FAX 303-273-3623) is located on the first floor of the W. Lloyd Wright Student Wellness Center at the corner of 18th and Elm Streets (1770 Elm Street). Nurse practitioners and registered nurses provide services by appointment Monday through Friday 8:00 am to 12:00 pm and 1:00 pm to 4:45 pm. Family medicine physicians provide services by appointment several days a week. After hours students can call New West Physicians at (303) 278-4600 to speak to the physician on call (identify yourself as a Mines student). The Health Center offers primary health care. For X-rays, specialists or hospital care, students are referred to appropriate providers in the community. More information is available at https://www.mines.edu/student-health/.

***Immunization Requirement:*** All incoming students are required to submit documented proof of specific vaccinations (https://portal.hartshorn.colostate.edu/ExternalAuth?returnUrl=%2F/) or laboratory evidence of immunity. These requirements are submitted through Trailhead, using the Health Portal icon on the main page. Detailed information on uploading this required information is available at https://www.mines.edu/student-health/student-health-center/forms/

- **Measles, Mumps, and Rubella (MMR) Vaccine**: Colorado law requires every student to submit proof of two (2) valid vaccinations for measles, mumps, and rubella (MMR) given no earlier than 4 days before the student's first birthday. There must be at least 28 calendar days between the two vaccinations.
- **Meningococcal ACWY Vaccine**: Colorado law requires all students living on campus in student housing to either submit proof of a Meningitis ACWY vaccine given within the last five years, or to sign the Meningococcal waiver form. If the 5-year period will expire while the student is living on campus, we recommend receiving another Meningococcal ACWY vaccine. Students will have a hold placed on their account 5 years after the date of the most recent Meningitis ACWY vaccine if they are still living on campus. Currently, Meningitis ACWY is required, not Meningitis B.
- **Tuberculosis:** Completion of the Tuberculosis questionnaire is required. This form is located in the Health Portal under the Forms tab. In some cases, TB testing may also be indicated.

**Dental Clinic:** The Dental Clinic is located on the second floor of the W. Lloyd Wright Wellness Center. Services include comprehensive exams, cleanings, fillings, x-rays and emergency services. Students who have paid the student health services fee are eligible for these services. The dental clinic is open Tuesdays, Wednesdays, and Fridays during the academic year with fewer hours in the summer. Services are by appointment only and can be made by calling the Dental Clinic, phone 303-273-3377. Dental care is on a fee-for-service basis at a fraction of the cost of other dental offices. For the fee schedule, please refer to our website, https://www.mines.edu/student-health/student-health-center/

dental-clinic/.  The Dental Clinic accepts cash or checks, as well as credit/debit cards.

***Fees:*** *Students are charged a mandatory health services fee each semester, which allows them access to services at the Health Center and Dental Clinic.*

***Student Health Insurance Plan (SHIP):*** *Having adequate health insurance is a condition of enrollment at Colorado School of Mines. All students are charged for the Student Health Insurance Plan (SHIP) and those students with approved waivers will see the waiver credit.* Enrollment confirmation or waiver of the Mines Student Health Insurance Plan is done online. The deadline to submit a waiver is Census Day.The SHIP office is located on the second floor of the W. Lloyd Wright Student Wellness Center.

***Student Health Insurance Plan--Adequate Health Insurance Requirement****: All degree seeking U.S. citizen and permanent resident students, and all international students regardless of degree status, are required to have health insurance. Students are automatically enrolled in the Student Health Insurance Plan and may waive coverage if they have coverage under a personal or employer plan that meets minimum requirements. International students must purchase the SHIP, unless they meet specific requirements. Information about the Mines Student Health Insurance Plan, as well as the criteria for waiving, is available online at* https://www.mines.edu/student-health/student-insurance/ *or by calling 303.273.3388.*

**Counseling Center:**  Located on the second floor of the W. Lloyd Wright Student Wellness Center, phone 303-273-3377. The Mines Counseling Center is staffed by licensed and experienced mental health professionals skilled in handling a variety of presenting concerns. Services are designed to assist students in resolving issues that interfere with their ability to successfully navigate the Mines journey. Services are confidential, voluntary and covered by student fees. The Counseling Center utilizes a Stepped Care model, which allows students to create a wellness plan that connects them with services that best meet their unique needs. Available service options include single-session consultation, skills-based workshops, online assisted therapy tools, brief therapy interventions, and care coordination to connect students with local providers for more intensive treatment needs. Updated service and resource information is available on our website: https://www.mines.edu/counseling-center/.

# Services

## Motor Vehicles Parking

*All motor vehicles on campus must be registered with the campus Parking Services Division of Facilities Management, 1318 Maple Street, and must display a Mines parking permit. Vehicles must be registered at the beginning of each semester or upon bringing your vehicle on campus, and updated whenever you change your address.*

## Public Safety

The Colorado School of Mines Department of Public Safety is a full service, community oriented law enforcement agency, providing 24/7 service to the campus. It is the mission of the Colorado School of Mines Police Department to make the Mines campus the safest campus in Colorado.

The department is responsible for providing services such as:

- Proactive patrol of the campus and its facilities
- Investigation and reporting of crimes and incidents
- Motor vehicle traffic and parking enforcement
- Crime and security awareness programs
- Alcohol / Drug abuse awareness / education
- Self defense classes
- Consultation with campus departments for safety and security matters
- Additional services to the campus community such as: vehicle unlocks and jumpstarts, community safe walks (escorts), authorized after-hours building and office access, and assistance in any medical, fire, or other emergency situation.

The police officers employed by the Department of Public Safety are fully trained police officers in accordance with the Peace Officer Standards and Training (P.O.S.T.) Board and the Colorado Revised Statute.

More information on the Mines Police Department is available at: https://www.mines.edu/campus-safety/

**Career Center**

The Mines Career Center mission is to assist students in developing, evaluating, and/or implementing career, education, and employment decisions and plans. Career development is integral to the success of Mines graduates and to the mission of Mines.

Students and recent graduates who develop, utilize and apply the services offered by the Mines Career Center will be educated, coached and empowered to conduct a strategic, personalized career exploration and ethical job search that highlights the passions, skills and strengths of each individual. In addition, students are offered opportunities to engage with companies and organization in a variety of forums to enhance their professional knowledge and diversity of career prospects.

Services are provided to all students and for all recent graduates, up to 24 months after graduation. Students must adhere to the ethical and professional business and job searching practices as stated in the Career Center Student Policy, which can be found in its entirety on the Student's Homepage of DiggerNet. In order to accomplish our mission, we provide a comprehensive array of career services:

***Career, Planning, Advice, and Counseling***

- “The Mines Strategy" a practical, user-friendly career manual with interview strategies, resume and cover letter examples, career exploration ideas, and job search tips;
- Online resources for exploring careers and employers at https://www.mines.edu/careers/;
- Individual job search advice, resume and cover letter critiques;
- Practice video-taped interviews;
- Job Search Workshops - successful company research, interviewing, resumes, professional branding, networking skills;
- Career resource library.

***Job Resources and Events***

- Career Day (Fall and Spring);
- Online job search system: DiggerNet;
- Job search assistance for on-campus jobs (work-study / student worker);

- Online and in-person job search assistance for internships, CO-OPs, and full-time entry-level job postings;
- On-Campus Student Worker Job Fair (Fall and Spring);
- Virtual Career Fairs and special recruiting events;
- On-campus interviewing - industry and government representatives visit the campus to interview students and explain employment opportunities;
- General employment board;
- Company research resource;
- Cooperative Education Program.

## Identification Cards (Blaster Card Office)

All new students must have a Blaster Card made as soon as possible after they enroll. The Blaster Card office also issues RTD College Passes, which allow students to ride RTD buses and light rail free of charge.

The Blaster Card can be used for student meal plans, to check material out of the Arthur Lakes Library, to access certain electronic doors, and may be required to attend various campus activities.

## Standards, Codes of Conduct

Students can access campus rules and regulations, including the student code of conduct, student honor code, alcohol policy, sexual misconduct policy, the unlawful discrimination policy and complaint procedure, public safety and parking policies, and the distribution of literature and free speech policy, by visiting the Mines Policy Library website at https://www.mines.edu/policy-library/. We encourage all students to review the electronic document and expect that students know and understand the campus policies, rules and regulations as well as their rights as a student. Questions and comments regarding the above mentioned policies can be directed to the Dean of Student's Office located in the Student Center Office, room 240.

## Student Publications

Two student publications are published at Mines. Opportunities abound for students wishing to participate on the staffs. A Board of Student Media acts in an advisory capacity to the publications staffs and makes recommendations on matters of policy.

The *Oredigger* is the student newspaper, published weekly during the school year. It contains news, features, sports, letters and editorials of interest to students, faculty, and the Golden community.

The literary magazine, *High Grade*, is published each semester. Contributions of poetry, short stories, drawings, and photographs are encouraged from students, faculty and staff.

## Veterans Services

The Registrar's Office provides veterans services for students attending the School and using educational benefits from the Veterans Administration.

# Activities

## **Office of** Student Activities, Involvement and Leadership **(**https://www.mines.edu/student-activities/**)**

The Office of Student Activities, Involvement and Leadership (SAIL) coordinates the various activities and student organizations on the Mines campus. Student government, professional societies, living groups, honor societies, interest groups and special events add a balance to the academic side of the Mines community. Participants take part in management training, event planning, and leadership development. To obtain an up-to-date listing of the recognized campus organizations or more information about any of these organizations, contact the SAIL office.

## Student Government

**The Graduate Student Government** was formed in 1991 and is recognized by Mines as the representative voice of the graduate student body. GSG's primary goal is to improve the quality of graduate education and offer academic support for graduate students.

**The Associated Students of Colorado School of Mines** (ASCSM) is sanctioned by the Board of Trustees of the School. The purpose of ASCSM is, in part, to advance the interest and promote the welfare of Mines and all of the students and to foster and maintain harmony among those connected with or interested in the School, including students, alumni, faculty, trustees and friends. Undergraduate Student Government (USG) and Graduate Student Government (GSG) are the governing bodies recognized by Mines through ASCSM as the representative voice of their respective student bodies. The goal of these groups is to improve the quality of education and offer social programming and academic support.

Through funds collected as student fees, ASCSM strives to ensure a full social and academic life for all students with its organizations, publications, and special events. As the representative governing body of the students ASCSM provides leadership and a strong voice for the student body, enforces policies enacted by the student body, works to integrate the various campus organizations, and promotes the ideals and traditions of the School.

**The Mines Activity Council** (MAC) serves as the campus special events board. The majority of all-student campus events are planned by MAC. Events planned by MAC include comedy shows to the campus on most Fridays throughout the academic year, events such as concerts, hypnotists, and one time specialty entertainment; discount tickets to local sporting events, theater performances, and concerts, movie nights bringing blockbuster movies to the Mines campus; and E-Days and Homecoming.

## Special Events

**Engineers' Days** festivities are held each spring. The three day affair is organized entirely by students. Contests are held in drilling, hand-spiking, mucking, and oil-field olympics to name a few. Additional events include a huge fireworks display, the Ore-Cart Pull to the Colorado State Capitol, the awarding of scholarships to outstanding Colorado high school seniors and an Engineers' Day concert.

**Homecoming** weekend is one of the high points of the year. Events include a football rally and game, campus decorations, election of Homecoming Queen and Beast, parade, burro race, and other contests.

**International Day** is planned and conducted by the International Council. It includes exhibits and programs designed to further the cause of understanding among the countries of the world. The international dinner and entertainment have come to be one of the campus social events of the year.

**Winter Carnival**, sponsored by Blue Key, is an all-school ski day held each year at one of the nearby ski areas. In addition to skiing, there are also fun competitions (snowman contest, sled races, etc.) throughout the day.

## Outdoor Recreation Program

The Outdoor Recreation Program is housed at the Mines Park Community Center. The Program teaches classes in outdoor activities; rents mountain bikes, climbing gear, backpacking and other equipment; and sponsors day and weekend activities such as camping, snowshoeing, rock climbing, and mountaineering.

## Residence Hall Association (RHA)

Residence Hall Association (RHA) is a student-run organization developed to coordinate and plan activities for students living in the Residence Halls. Its membership is represented by students from each hall floor. Officers are elected each fall for that academic year. For more information, go to RHA (https://www.mines.edu/residence-life/residence-hall-association/).

## Student Organizations

**Social Fraternities and Sororities** - There are seven national fraternities and three national sororities active on the Mines campus. Fraternities and Sororities offer the unique opportunity of leadership, service to one's community, and fellowship. Greeks are proud of the number of campus leaders, athletes and scholars that come from their ranks. Colorado School of Mines chapters are:

- Alpha Phi
- Alpha Tau Omega
- Beta Theta Pi
- Kappa Sigma
- Phi Gamma Delta
- Pi Beta Phi
- Sigma Alpha Epsilon
- Sigma Kappa
- Sigma Nu
- Sigma Phi Epsilon

**Honor Societies** - Honor societies recognize the outstanding achievements of their members in the areas of scholarship, leadership, and service. Each of the Mines honor societies recognizes different achievements in our students.

**Special Interest Groups -** Special interest organizations meet the special and unique needs of the Mines student body by providing co-curricular activities in specific areas.

**International Student Organizations** - The International Student Organizations provide the opportunity to experience a little piece of a different culture while here at Mines, in addition to assisting the students from that culture adjust to the Mines campus.

**Professional Societies** - Professional Societies are generally student chapters of the national professional societies. As a student chapter, the professional societies offer a chance for additional professional development outside the classroom through guest speakers, trips, and interactive discussions about the current activities in the profession. Additionally, many of the organizations offer internship, fellowship and scholarship opportunities.

**Recreational Organizations** - The recreation organizations provide the opportunity for students with similar interests to participate as a group in these recreational activities. Most of the recreational organizations compete on both the local and regional levels at tournaments throughout the year.

For a complete list of all currently registered student organizations, please visit the SAIL office or website at https://www.mines.edu/student-activities/.

# Registration and Tuition Classification

## General Registration Requirements

The normal full-time credit load for graduate students is 9 credit hours per term.

Full-time graduate students may register for an overload of up to 6 credit hours (up to 15 credit hours total) per term at no increase in tuition. Subject to written approval by their advisor and department head or division director, students may register for more than 15 credit hours per term by paying additional tuition at the regular part-time rate for all hours over 15. The maximum number of credits for which a student can register during the summer is 12.

Students in any of the following categories must register as full-time students.

- International on-campus students subject to immigration requirements. This applies to international students holding J-1 and F-1 visas.
- Students receiving financial assistance in the form of graduate teaching assistantships, research assistantships, fellowships or hourly contracts.
- Students enrolled in academic programs that require full-time registration. Refer to the degree program sections of this catalog to see if this applies to a particular program.

Special cases to the full-time registration requirement for students listed above are under Full Time Status-Required Course load and include first-year international students who must receive special instruction to improve their language skills, and thesis based students who have completed their credit-hour requirements, have completed all required paperwork, are eligible for reduced registration and are working full time on their thesis (see section on reduced registration). To remain active in their degree program, all graduate students must register continuously each fall and spring semester. If not required to register full-time, students may register as a part-time student for any number of credit hours (1.0 credit hour minimum). Students who wish to take a semester off must submit the Leave of Absence paperwork, or the degree will be terminated.

Summer registration is not required to maintain an active program. Students who continue to work on their degree program and utilize Mines facilities during the summer, however, must register. Students registered during the summer are assessed regular tuition and fees.

New graduate students are expected to register for and pay for credits for the admittance term, including summer admittance.

Graduate students who register for credits in any term are responsible for payment for those credits. Payment information can be found here: https://www.mines.edu/controllers-office/accounts-receivable-and-cashiering/.

Graduate students who wish to be dropped from all credits in a term must either submit the Leave of Absence paperwork or the Withdrawal from Graduate School paperwork by Census Day of that term. Students who submit either form after census may be withdrawn from credits, but will still owe the portion of tuition and fees due at the time of withdrawal.

It is the student's responsibility to submit either the Leave of Absence form or the Withdrawal from Graduate School form. Students who wish to be dropped or withdraw from all credits, but do not submit either the Leave of Absence form or the Withdrawal form will be responsible for paying all the tuition and fees.

## Research Registration

In addition to completing prescribed course work and defending a thesis, students in thesis-based degree programs must complete a research experience under the direct supervision of their faculty advisor or co-advisor. Master students must complete a minimum of 6* hours of research credit, and doctoral students must complete a minimum of 24* hours of research credit at Mines. While completing this experience, students register for research credit under course numbers 707. Faculty assign grades indicating satisfactory or unsatisfactory progress based on their evaluation of the student's work. Students registered for research during the summer semester and working on campus must pay regular tuition and thesis research fees for summer semester. Students may not transfer research credits from other institutions, so students working on research abroad must either register for research credits at Mines or submit the Leave of Absence paperwork. Those who take the leave of absence may not use any Mines campus resources, including, but not limited to consultations with advisors, committee members and other Mines students during the term of leave.

* Departmental requirements may require students to complete more than the institutional minimum number of research credits.

## Eligibility for Reduced Registration

Students enrolled in thesis-based degree programs who have completed a minimum number of course and research credit hours in their degree programs are eligible to continue to pursue their graduate program as full-time students at a reduced registration level. In order to be considered for this reduced, full-time registration category, students must satisfy the following requirements:

1. For M.S. students,
    a. Completion of 36 hours of eligible course, research, and transfer credits combined, and
    b. Paid for 27 credits.
        i. 1-9 credits per semester count as paid credits; 10-15 credits do not count as paid credits.
2. For PhD students,
    a. Completion of 72 hours of eligible course, research, and transfer credits combined, and
    b. Paid for 54 credits.
        i. 1-9 credits per semester count as paid credits; 10-15 credits do not count as paid credits.
3. For all students, an approved Committee form and Degree Audit form must be on file in the Graduate Office the semester prior to one for which you are applying for reduced registration*.
4. PhD students must submit an approved Admission to Candidacy form by the first day of class in which the student would like reduced registration*.

* See OGS Graduation Deadlines website for specific deadlines (https://www.mines.edu/graduate-studies/graduation-deadlines/). Students who are eligible for reduced registration are considered full time if they register for 4 credit hours of research under course number 707.

## Full-time Status - Required Course Load

To be deemed full-time during the fall and spring semesters, students must register for at least 9 credit hours. In the event a thesis-based student has completed his or her required course work and research credits, has completed all required forms, and has received confirmation from the Office of Graduate Studies that (s)he is eligible for reduced registration, the student will be deemed full-time if he or she is registered for at least 4 credit hours of research credit.

Student enrollment is not required during the summer semester for continuing Mines students or students who hold valid F-1 visa status. An international student who is not in valid F1 visa status and beginning their degree program in the US for the first time, must be enrolled as a full time student during their first summer semester. To be considered full-time during their first summer semester, a student must register for a minimum of 4 credit hours.

## Late Registration Fee

Students must complete their registration by the date specified in the Academic Calendar. Students who fail to complete their registration during this time will be assessed a $100 late registration fee and will not receive any tuition fellowships for which they might otherwise be eligible.

## Reciprocal Registration

Under the Reciprocal Exchange Agreement Between the State Supported Institutions in Northern Colorado, Mines graduate students who are paying full-time tuition may take courses at Colorado State University, University of Northern Colorado, and University of Colorado (Boulder, Denver, Colorado Springs, and the Health Sciences Center) at no charge by completing the request form and meeting the required conditions on registration and tuition, course load, and course and space availability. Request forms are available from the Registrar's Office and requests for reciprocal course credits are subject to approval by participating schools.

Courses completed under the reciprocal agreement may be applied to a student's degree program, with departmental approval. These are, however, applied as transfer credit into the degree program. In doing so, they are subject to all the limitations, approvals and requirements of any regularly transferred course.

## Transfer Credits

With prior approval, graduate students may use transfer coursework credits towards a graduate level degree. All transfer credits must be listed on the Degree Audit form and have the appropriate signatures of approval.

- Master's non-thesis and professional master's students must receive approval from the advisor, co-advisor (if applicable), minor representative (if applicable) and department head.
- Master's thesis and PhD students must receive approval from the advisor, co-advisor (if applicable), all committee members, minor representative (if applicable) and the department head.

Transfer credit limitations apply to all major and minor degrees. Transfer credits may be from a Mines undergraduate transcript or from another university.

- Transfer credits from a Mines undergraduate transcript must be 400 level or higher (graduate students are limited to no more than 9 credits of 400 level coursework), may not have been used towards an undergraduate degree, cannot be for prerequisites or deficiency credits and must have a grade of C or better*.
- Transfer credits from other universities must be for course work (research credits cannot be transferred), graduate level with a grade of "C " or better, cannot have been used towards an undergraduate degree and cannot be for prerequisite or deficiency credits. Credits without a letter grade (Pass/Fail, Satisfactory/Unsatisfactory, etc.) will not be accepted as transfer credit.

* Some degree programs require grades higher than a C to use as transfer credit. Please refer to the individual degree programs for specifics.

Grades for transfer credits, either from a Mines undergraduate transcript or from another university, will not be transferred and therefore will not impact the students graduate G.P.A.

The Office of Graduate Studies must have official transcripts on file prior to transferring credit from another university. The exception is transfer credits taken under the Reciprocal Agreement, in which case the Registrar's Office must receive the grade from the transfer institution prior to transferring the credit.

Due to time constraints of receiving transcripts and grades, students taking transfer credits in their last semester may not be able to graduate in that semester. Students studying abroad are encouraged to not study abroad during their last semester.

Major degree transfer credit limitations:

- 30 credit Master's non-thesis degree programs are limited to no more than 9 transfer credits.
- 36 credit Master's non-thesis degree programs are limited to no more than 15 transfer credits.
- 30-38 credit Master's thesis degree programs are limited to no more than 9 transfer credits.
- PhDs transferring a thesis based master's degree from another university* may transfer no more than 36 credits.
- PhDs transferring individual coursework, or any graduate level degree other than a thesis based master's degree from another university* may transfer no more than 24 credits.
    - *Any credit taken at Mines and listed on a Mines graduate level transcript are not transfer credits.
    - *PhDs may, with committee and department head approval, use all credits from a Mines Master's degree towards a PhD, as long as the credits were not used towards two (2) Mines Master's degrees.

Minor degree transfer credit limitations:

- Less than half of the minor credit requirement may be transfer credits.
    - Master's students may transfer no more than 4.0 credits towards a minor
    - PhD students may transfer no more than 5.5 credits towards a minor.

Transfer credit conversion

Colorado School of Mines uses semester credits. Any transfer credits taken at a university that does not use semester credits will have the credits converted. U.S. Quarter credit hours are equivalent to 2/3 semester credit hours. European Credit Transfer and Accumulation System (ECTS) credits are equivalent to ½ semester credit hours. Other credits will be assessed on an individual basis.

## Dropping and Adding Courses

Students may add or drop some, but not all credits, through web registration without paying a fee during the add/drop period listed on the academic calendar. Graduate students who wish to drop all credits during the fall or spring term must submit either the Leave of Absence or Withdrawal from Graduate School paperwork by census day.

## Withdrawing from Courses

After the add/drop date students may withdraw through web registration from some credits, but not all for any reason with a grade of “W” through the last day to withdraw noted on the academic calendar. Students who wish to withdraw from all credits must submit a Leave of Absence form or a Withdrawal from Graduate School form.

After the last day to withdraw on the Academic Calendar no withdrawals are permitted, except in case of withdrawal from school. For extenuating circumstances contact the Graduate Dean.

Any student on leave must submit a Return from Leave form (https://www.mines.edu/graduate-studies/forms/return-leave-absence/) that includes documentation that the problems which caused the withdrawal have been corrected. The student will be reinstated to active status upon approval by their advisor and their department head or division director.

Students who have already used 2 semesters of leave will need to submit the Withdrawal from Graduate School form. Students who withdraw from graduate school will need to re-apply for admission online and be re-accepted before returning to school.

The financial impact of a withdrawal is covered in the section on “Payments and Refunds.”

## Auditing Courses

As part of the maximum of 15 semester hours of graduate work, students may enroll for no credit (NC) in a course with the permission of the instructor. Tuition charges are the same for no credit as for credit enrollment.

Students must enroll for no credit before census day, the last day of registration. The form to enroll for a course for no credit is available in the Registrar’s Office. NC designation is awarded only if all conditions stipulated by course instructors are met.

Mines requires that all U.S. students who are being supported by the institution register full time, and federal financial aid regulations prohibit us from counting NC registration in determining financial aid eligibility. In addition, the INS requires that international students register full time, and we are discouraged from counting NC registration toward that requirement. Furthermore, there are no consistent standards for expectations of students who register for NC in a course. Therefore, in order to treat all Mines students consistently, NC registration will not count toward the minimum number of hours for which students are required to register. This includes the minimum continuous registration requirement of part-time students and the 9 credit-hour requirement for students who must register full time.

The reduced registration policy is based on the principle that the minimum degree requirement (36 or 72 hours) would include only the credits applied toward that degree. Deficiency and extra courses are above and beyond that minimum. NC courses fall into the latter category and may not be applied toward the degree. Therefore, NC registration will not count toward the number of hours required to be eligible for reduced thesis registration.

NC registration may involve additional effort on the part of faculty to give and/or grade assignments or exams, so it is the institution’s policy to charge tuition for NC courses. Therefore, NC registration will count toward the maximum number of credits for which a graduate student may be allowed to register. This includes a tuition surcharge for credits taken over 15.

## Off-Campus Study

A student must enroll in an official Mines course for any period of off-campus, course-related study, whether U.S. or foreign, including faculty-led short courses, study abroad, or any off-campus trip sponsored by Mines or led by a Mines faculty member. The registration must occur in the same term that the off-campus study takes place. In addition, the student must complete the necessary release, waiver, and emergency contact forms, transfer credit pre-approvals, and FERPA release, and provide adequate proof of current health insurance prior to departure. For additional information concerning study abroad requirements, contact the Office of International Programs at (303) 384-2121; for other information, contact the Registrar’s Office.

Students conducting research off campus must either register for research credits at Mines or submit the Leave of Absence paperwork. Students on leave may not use any campus resources, including work with advisor, committee members and any Mines students.

Students conducting research abroad must comply with the research off-campus rules above and need to register with the Study Abroad Office. Students may not transfer research credits from another university. All graduate students must register for credits at the Colorado School of Mines for at least one semester. A semester of study abroad does not count towards this requirement.

Students on study abroad who are using study abroad transfer credits towards a degree program must have official transcripts on file with the Registrar's Office prior to graduation. Since foreign transcripts often take longer to arrive than US transcripts, students on study abroad during their last semester, may not be able to graduate in that same semester.

Please note if you are an online student please visit: Mines Online (https://online.mines.edu/) for additional information on services and support.

### Numbering of Courses

Course numbering is based on the content of material presented in courses:

| Material | Level | Division |
|---|---|---|
| 100-199 | Freshman Level | Lower Division |
| 200-299 | Sophomore Level | Lower Division |
| 300-399 | Junior Level | Upper Division |

| | | |
|---|---|---|
| 400-499 | Senior Level | Upper Division |
| 500-599 | Master's Level | |
| 600-699 | Doctoral Level | |
| Over 700 | Graduate Research or Thesis Level | |

# Graduation Requirements

## Graduation REGISTRATION and Checkout Requirements

To graduate, students must be registered during the term in which they complete their program. An exception to this registration policy allows students to complete an early checkout by census day of the graduation semester. Early checkout is accepted by the Office of Graduate Studies and allows students to graduate in a term, without registering:

- checkout by Summer census to graduate in August or December and avoid summer & fall registration,
- checkout by Fall census to graduate in December and avoid fall registration, and
- checkout by Spring census to graduate in May and avoid spring registration.

Students not meeting this checkout deadline are required to register for an additional semester before the Office of Graduate Studies will process their checkout request. For additional information, refer to https://www.mines.edu/graduate-studies/graduation-deadlines/.

All graduating students must officially check out of their degree program. Checkout forms will be sent by the Graduate Office after a student has applied to graduate in Trailhead and must be completed and returned by the established deadline. Students must register for the graduation term, unless the checkout process is completed by census day of the graduation term.

For detailed information on Graduation, please see the Graduation tab under Academic Regulations.

# Leave of Absence & Parental Leave

## Leave of Absence

Leaves of absence are granted when it is temporarily impossible for students to continue to work toward a degree. Leave of absence requests for the current semester must be received by the Office of Graduate Studies (OGS) prior to census. Leave forms submitted after census may be considered, but students may only be withdrawn from credits, not dropped. The financial impact of requesting a leave of absence for the current semester is covered in the section on “Payments and Refunds (https://catalog.mines.edu/graduate/tuitionfeesfinancialassistance/)”. Leave of absence requests for prior semesters will not be considered.

Any request for a leave of absence must have the prior approval of the student’s faculty advisor, the Office of International Programs (international students only), Financial Aid and the Graduate Dean. To request a leave of absence, students must submit the Leave of Absence form, along with the following information:

1. the reasons why the student must interrupt his or her studies and,
2. a plan (including a timeline and deadlines) for resuming and completing the work toward the degree in a timely fashion.

Students on leave remain in good standing even though they are not registered for any course or research credits. While on leave, however, students will not have access to Mines resources. This includes, but is not limited to, office space, computational facilities, library, faculty and other Mines students. Students who will be using campus resources in any manner will not be allowed to take a leave and will be required to register for at least one credit.

Students are limited to two, not necessarily consecutive, regular semesters of leave while in a graduate degree program at Mines. Beyond these two semesters, students needing to suspend their degree programs further are required to formally withdraw from the degree program by submitting the Withdrawal from Graduate School paperwork.

Students on a leave of absence must submit the Return from Leave paperwork within the time frame allowed to continue in the degree program. Students on leave who do not submit the Return from Leave paperwork and do not submit the Withdrawal from Graduate School form will have the degree program terminated, will need to re-apply for admission, be re-admitted and pay a $200 re-admission fee.

Students who withdraw from graduate school need to re-apply, and be readmitted, into the degree program before continuing in the degree program. As with all degree program applications, applications from candidates returning from a leave are reviewed by the program and considered for readmission at the sole discretion of the program.

Students who fail to register and who are not on approved leaves of absence have their degree programs terminated. Students who wish to return to graduate school after an unauthorized leave of absence must apply for readmission and pay a $200 readmission fee.

## Parental Leave

Graduate students in thesis-based degree programs, who have full-time student status and receive TA/RA support at 0.5 FTE level or higher, may be eligible to request up to eight (8) weeks of parental leave. The Parental Leave Policy is designed to assist students who are primary child-care providers immediately following the birth or adoption of a child. The Policy is designed to make it possible for students to maintain full-time status in research-based degree programs while taking a leave from that program to care for their new child, and facilitate planning for continuance of their degree program.

Nothing in the Parental Leave policy can, or is intended to replace communication and cooperation between the student and his or her advisor, and the good-faith efforts of both to accommodate the birth or adoption of a child within the confines and expectations of participating in a research-active graduate degree program. It is the intent of this Policy to reinforce the importance of this cooperation, and to provide a framework of support and guidance.

### Eligibility

In order to be eligible for Parental Leave, a graduate student must:

- be the primary child care provider;
- have been a full-time graduate student in his/her degree program during at least the two (2) prior consecutive semesters;
- be enrolled in a thesis-based degree program (i.e., Doctoral or thesis-based Masters);
- be in good academic standing as defined in the Unsatisfactory Academic Performance section of this Catalog;
- provide a letter from a physician or other health care professional stating the anticipated due date of the child, or provide appropriate documentation specifying an expected date of adoption of the child;
- notify advisor of intent to apply for Parental Leave at least four (4) months prior to the anticipated due date or adoption date; and
- at least two (2) months prior to the expected leave date complete, and have approved, the Request for Parental Leave Form that includes an academic Program Plan for program continuance.

### Exceptions and Limitations

This Policy has been explicitly constructed with the following limitations:

- part-time and non-thesis students are not eligible for Parental Leave. These students may, however, apply for a Leave of Absence through the regular procedure defined above;
- if both parents are Mines graduate students who would otherwise qualify for leave under this Policy, each is entitled to a Parental Leave period immediately following the birth or adoption of a child during which he or she is the primary care provider, but the leaves may not be taken simultaneously; and
- leaves extending beyond eight (8) weeks are not covered by this Policy. The regular Leave of Absence policy defined in the Graduate Catalog applies to these cases.

### Benefits

Under this Policy students will receive the following benefits and protections:

- continuance of assistantship support during the semester in which the leave is taken - only if the student is funded through TA/RA Contract;
- maintenance of full-time status in degree program while on Parental Leave; and
- documentation of an academic plan that specifies both how a student will continue work toward his or her degree prior to the leave period

and how a student will reintegrate into a degree program after returning from leave.

## Planning and Approval

It is the student's responsibility to initiate discussions with his/her advisor(s) at least four (4) months prior to the anticipated birth or adoption. This notice provides the lead time necessary to rearrange teaching duties (for those students supported by teaching assistantships), to adjust laboratory and research responsibilities and schedules, to identify and develop plans for addressing any new health and safety issues, and to develop an academic Program Plan that promotes seamless reintegration back into a degree program.

While faculty will make every reasonable effort to meet the needs of students requesting Parental Leave, students must recognize that faculty are ultimately responsible for ensuring the rigor of academic degree programs and may have a direct requirement to meet specific milestones defined in externally funded research contracts. Within this context, faculty may need to reassess and reassign specific work assignments, modify laboratory schedules, etc. Without good communication, such efforts may lead to significant misunderstandings between faculty and students. As such, there must be good-faith, and open communication by each party to meet the needs and expectations of each during this potentially stressful period.

The results of these discussions are to be formalized into an academic Program Plan that is agreed to by both the student and the advisor(s). This Plan, to be accepted, must also receive approval by the appropriate Department Head, Division or Program Director and the Graduate Dean. Approval of the Dean should be sought by submitting to the Office of Graduate Studies a formal Parental Leave request, with all necessary signatures along with the following documentation:

- a letter from a physician or other health care professional stating the anticipated due date of the child or other appropriate documentation specifying an expected date of adoption of the child; and
- the advisor(s) and Department Head, Division or Program Director approved academic Program Plan.

These materials should be delivered to the Office of Graduate Studies no less than two (2) months prior to the anticipated date of leave.

If a student and faculty member cannot reach agreement on a Program Plan, they should consult with the appropriate Department Head, Division or Program Director to help mediate and resolve the outstanding issues. As appropriate, the Department Head, Division or Program Director may request the Graduate Dean and the Director of the Women in Science, Engineering and Mathematics (WISEM) program provide additional assistance in finalizing the Program Plan.

## Graduate Students with Appointments as Graduate Research and Teaching Assistants

A graduate student who is eligible for Parental Leave and has a continuing appointment as a research or teaching assistant is eligible for continued stipend and tuition support during the semester(s) in which the leave is taken. For consideration of this support, however, the timing of a leave with continued stipend and tuition support must be consistent with the academic unit's prior funding commitment to the student. No financial support will be provided during Leave in a semester in which the student would have otherwise not been funded.

*Tuition and Fee Reimbursement:* If the assistantship, either teaching or research, would have normally paid a student's tuition and mandatory fees, it will continue to do so for the semester(s) in which the Leave is taken. Costs for tuition will be shared proportionally between the normal source of funding for the research or teaching assistantship and the Office of Graduate Studies.

*Stipend Support:* Stipends associated with the assistantship will be provided at their full rate for that portion of the semester(s) during which the student is not on Parental Leave. No stipend support need be provided during the time period over which the Parental Leave is taken. The student may, however, choose to have the stipend he or she would receive during the semester(s) in which the Leave is taken delivered in equal increments over the entire semester(s).

While on Leave, students may elect to continue to work in some modified capacity and Faculty, Departments and Programs may elect to provide additional stipend support in recognition of these efforts. Students, however, are under no obligation to do so, and if they choose to not work during their Leave period this will not be held against them when they return from Leave. Upon return, students on Research Assistantships are expected to continue their normal research activities as defined in their Academic Plans. Students on Teaching Assistantships will be directed by the Department, Division or Program as to specific activities in which they will engage upon return from Parental Leave.

## Registration

Students on Parental Leave should register at the full-time level for research credit hours under the direction of their Thesis Advisor. The advisor will evaluate student progress toward degree for the semester in which Parental Leave is taken only on those activities undertaken by the student while he or she is not on Leave.

# In-State Tuition Classification Status

## In-State Tuition Classification Status

### General Information

The State of Colorado partially subsidizes the cost of tuition for all students whose domicile, or permanent legal residence, is in Colorado. Each Mines student is classified as either an “in-state resident” or a “non-resident” at the time of matriculation. These classifications, which are governed by Colorado law, are based upon information furnished by each student on his or her application for admission to Mines. A student who willfully furnishes incorrect information to Mines to evade payment of non-resident tuition shall be subject to serious disciplinary action.

It is in the interest of each graduate student who is a U.S. citizen and who is supported on an assistantship or fellowship to become a legal resident of Colorado at the earliest opportunity. Typically, students on an assistantship contract that covers tuition and fees will have the non-resident portion of the tuition paid by Mines during their first year of study only. U.S. citizens are expected to obtain Colorado residency status by the end of the first year of study. After the first year of study, these students who do not obtain residency status may be responsible for paying the difference between resident and non-resident tuition. International students on an assistantship contract that covers tuition and fees will have the non-resident portion of the tuition paid by Mines beyond the $1^{st}$ year.

### Requirements for Establishing In-State Residency

The specific requirements for establishing residency for tuition classification purposes are prescribed by state law (Colorado Revised Statutes, Title 23, Article 7). Because Colorado residency status is governed solely by Colorado law, the fact that a student might not qualify for in-state status in any other state does not guarantee in-state status in Colorado. The tuition classification statute places the burden of proof on the student to provide clear and convincing evidence of eligibility.

In-state or resident status generally requires domicile in Colorado for the year immediately preceding the beginning of the semester in which in-state status is sought. “Domicile” is “a person’s true, fixed and permanent home and place of habitation.” An unemancipated minor is eligible for in-state status if at least one parent (or his or her court-appointed guardian) has been domiciled in Colorado for at least one year. If neither of the student’s parents are domiciliaries of Colorado, the student must be a qualified person to begin the one-year domiciliary period. A “qualified person” is someone who is at least twenty-two years old, married, or emancipated. A student may prove emancipation if:

1. The student’s parents have entirely surrendered the right to the student’s custody and earnings;
2. The student’s parents are no longer under any duty to financially support the student; and
3. The student’s parents have made no provision for the continuing support of the student.

To begin the one-year domiciliary period, a qualified person must be living in Colorado with the present intention to reside permanently in Colorado. Although none of the following indicia are determinative, voter registration, driver’s license, vehicle registration, state income tax filings, real property interests, and permanent employment (or acceptance of future employment) in Colorado will be considered in determining whether a student has the requisite intention to permanently reside in Colorado. Once a student’s legal residence has been permanently established in Colorado, he or she may continue to be classified as a resident student so long as such residence is maintained, even though circumstances may require extended temporary absences from Colorado.

For more information about the requirements for establishing in-state residency, please contact the Registrar’s Office (https://www.mines.edu/registrar/in-state-tuition/).

### Petitioning for In-State Tuition Classification

A continuing, non-resident student who believes that he or she has become eligible for in-state resident tuition due to events that have occurred subsequent to his or her initial enrollment may file a Petition for In-State Tuition Classification with the Registrar’s Office. This petition is due in the Registrar’s Office no later than the first day of the semester for which the student is requesting in-state resident status. Upon receipt of the petition, the Registrar will initially decide whether the student should be granted in-state residency status. The Registrar’s decision may be appealed by petition to the Tuition Classification Review Committee. For more information about this process, please contact the Registrar’s Office (http://inside.mines.edu/Petitioning-for-In-State-Tuition-Classification/).

### In-State Tuition Classification for WICHE Program Participants

WICHE, the Western Interstate Commission for Higher Education, promotes the sharing of higher education resources among the participating western states. Under this program, residents of Alaska, Arizona, California, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming who are enrolled in qualifying graduate programs may be eligible for in-state tuition classification. Current qualifying programs include:

- Applied Chemistry
- Environmental Engineering Science
- Geochemistry
- Geological Engineering
- Hydrology
- Mineral and Energy Economics
- Petroleum Engineering
- Underground Construction & Tunnel Engineering

Contact the Office of Graduate Studies (https://www.mines.edu/graduate-admissions/contact/) for more information about WICHE.

# Academic Regulations

## Graduate School Catalog

It is the responsibility of the graduate student to become informed and to observe all regulations and procedures required by the program the student is pursuing. Ignorance of a rule does not constitute a basis for waiving that rule. The current Graduate Catalog when a graduate student first enrolls, gives the academic requirements the student must meet to graduate. However, with department consent, a student can change to the requirements in a later catalog published while the student is enrolled in graduate school. Changes to administrative policies and procedures become effective for all students as soon as the campus community is notified of the changes.

The Graduate Catalog is available to students in both print and electronic forms. Print catalogs are updated annually. Electronic versions of the Graduate Catalog may be updated more frequently to reflect changes approved by the campus community. As such, students are encouraged to refer to the most recently available electronic version of the Graduate Catalog. This version is available at the Mines website. The electronic version of the Graduate Catalog is considered the official version of this document. In case of disagreement between the electronic and print versions, the electronic version takes precedence.

## Resolution of Conflicting Catalog Provisions

If a conflict or inconsistency is found to exist between these policies and any other provision of the Mines Graduate Catalog, the provisions of these policies shall govern the resolution of such conflict or inconsistency.

## Curriculum Changes

The Mines Board of Trustees reserves the right to change any course of study or any part of the curriculum to respond to educational and scientific developments. No statement in this Catalog or in the registration of any student shall be considered as a contract between Colorado School of Mines and the student.

## Making up Undergraduate Deficiencies

If the department or division decides that new students do not have the necessary background to complete an advanced degree, they will be required to enroll in courses for which they will receive no credit toward their graduate degree, or complete supervised readings, or both. Students are notified of their apparent deficiency areas in their acceptance letter from the Graduate School or in their first interview with their department advisor. Departments will provide the list of deficiencies to the students no later than one week after the start of classes of their first semester in order to allow them to add/drop courses, as necessary. Grades for these deficiency courses are recorded on the student’s transcript, become part of the student’s permanent record, and are calculated into the overall graduate GPA and could impact a student's academic standing. Students whose undergraduate records are deficient should remove all deficiencies as soon as possible after they enroll for graduate studies.

## Graduate Students in Undergraduate Courses

Students may apply toward graduate degree requirements a maximum of nine (9.0) semester hours of department-approved 400-level course work not taken to remove deficiencies and not taken as a degree requirement for a bachelor's degree upon the recommendation of the graduate committee and the approval of the Graduate Dean.

Students may apply toward graduate degree requirements 300-level courses only in those programs which have been recommended by the department, are not taken to remove deficiencies, are not taken as a degree requirement for a bachelor’s degree and have been approved by the Graduate Council before the student enrolls in the course. In that case, a maximum of nine (9.0) total hours of 300- and 400-level courses will be accepted for graduate credit towards a master’s or PhD or a maximum of three (3.0) total hours of 300-and 400-level courses will be accepted for a graduate certificate.

## Withdrawing from School

To officially withdraw from Mines, a graduate student must submit a Withdrawal from Graduate School form to the Office of Graduate Studies. If the form is submitted by census day, the student will be dropped from all credits and receive a full refund. If the form is submitted after Census Day, the student will receive grades of W in courses in progress and will be charged the amount due at the time of withdrawal (see the Payment and Refund section). If the student does not officially withdraw, the course grades are recorded as F’s and the student will be responsible for the tuition and fees due. Leaving school without having paid tuition and fees will result in the encumbrance of the transcript. Federal aid recipients should check with the financial aid office to determine what impact a withdrawal may have on current or future aid.

Students who leave school without submitting a Withdrawal from Graduate School form, but decide to return at a later date, will need to apply for admission and be re-admitted.

PhD students planning to voluntarily withdraw from their doctoral program may potentially depart Mines with an earned Master’s Degree. Approval is subject to review of student academic performance, including earned credit for coursework and/or research. For more information on this potential pathway, students should speak with their Faculty Advisor or the Dean of Graduate Studies. The Office of the Graduate Dean is responsible for oversight and administration of this pathway. While the Graduate Dean ultimately approves the student request, all relevant parties including the Faculty Advisor or departmental leadership will be included. This option is not applicable to those seeking temporarily leave from Mines.

# Graduate Grading System

## Grades

When a student registers in a graduate (500- and 600-level ) course, one of the following grades will appear on the academic record. Grades are based on the level of performance and represent the extent of the student's demonstrated mastery of the material listed in the course outline and achievement of the stated course objectives. These are Mines' grade symbols and their qualitative interpretations:

| Symbol | Interpretation |
|---|---|
| A | Acceptable for Graduate Credit |
| A- | Acceptable for Graduate Credit |
| B+ | Acceptable for Graduate Credit |
| B | Acceptable for Graduate Credit |
| B- | May be Acceptable for Graduate Credit |
| C+ | May be Acceptable for Graduate Credit |
| C | May be Acceptable for Graduate Credit |
| C- | May be Acceptable for Graduate Credit |
| D+ | Not Acceptable for Graduate Credit |
| D | Not Acceptable for Graduate Credit |
| D- | Not Acceptable for Graduate Credit |
| F | Failed |
| S | Satisfactory (C- or better, used as a mid-term grade) |
| U | Unsatisfactory (below C-, used as a mid-term grade) |
| INC | Incomplete |
| PRG | Satisfactory Progress |
| PRU | Unsatisfactory Progress |

Graduate students enrolled in undergraduate-level courses (400-level and below) are graded using the undergraduate grading system, but any undergraduate course taken while a graduate student will appear on the graduate level transcript and will impact the graduate level GPA. See the Mines Undergraduate Catalog (https://catalog.mines.edu/undergraduate/) for a description of this system.

Any undergraduate taking graduate-level credit must complete the 500 level form and agree to the specific terms selected.

- Students requesting the credit for undergraduate credit or those who do not qualify to have the credits listed on the graduate transcripts will have the credit listed on the undergraduate transcripts and the credit will impact the undergraduate GPA.
- Students who request the credit for graduate credit only and meet the qualifications to have the credits listed on the graduate level transcript will have the credits listed on the graduate level transcripts and the credits will impact the graduate level GPA.

In addition to these performance symbols, the following is a list of additional registration symbols that may appear on a Mines transcript:

| Symbol | Interpretation |
|---|---|
| WI | Involuntarily Withdrawn |
| W | Withdrew, No Penalty |
| T | Transfer Credit |
| NC | Not for Credit |
| Z | Grade not yet Submitted |

## Incomplete Grade

An Incomplete ‘INC’ is a temporary grade which may be given at the instructor’s discretion to a student when illness, necessary absence, or other reasons beyond the control of the student prevent completion of course requirements by the end of the academic term. An ‘INC’ is restricted to cases in which the student satisfactorily completed a significant amount of the course work, including attendance and participation.

The student and the instructor should discuss the terms for the incomplete before the end of the term. The instructor may grant up to one year, but the time limit may be less, to complete outstanding coursework. Any outstanding grade of ‘INC’ will be converted to an ‘F’ grade if it has not been updated by the instructor after one year. In the event that an ‘INC’ grade remains on the record at the completion of the degree, the ‘INC’ will be converted to an ‘F’ and included in the final GPA.

## Satisfactory Progress Grades

A graduate student may receive a grade of Satisfactory Progress, PRG, in either one of three possible situations:

1. As a passing grade given in a course that is graded pass-fail,
2. As a grade for a course extending more than one semester or
3. As a grade indicating completion of research credit hours.

When applied to pass-fail courses, the Satisfactory Progress grade, PRG, indicates successful completion of the requirements of the course. A grade of Unsatisfactory Progress, PRU, as applied to pass-fail courses, indicates the student failed to meet the requirements for successful completion of the course. The PRG and PRU grades have no point value toward a student's GPA. As described in the Unsatisfactory Academic Performance (https://catalog.mines.edu/graduate/generalregulations/academicperformance/) portion of this Catalog receipt of a PRU grade indicates unsatisfactory progress toward degree completion and will trigger academic disciplinary proceedings.

For students completing independent study or seminar courses extending over multiple terms, the progress grade has no point value. In such cases, the student receives a grade of PRG (progress). For multi-term independent study courses, upon completion of course requirements, a final letter grade is assigned in the last term in which the student enrolled in the course. In seminar courses in which continuous enrollment is required by the degree program, the PRG grade remains on all previous terms, with the option of either assigning a PRG grade or a final letter grade the last term of attendance.

When applied to research credits, the Satisfactory Progress grade, PRG, also has no point value toward a student's GPA, but indicates satisfactory progress toward completion of the research component of a student's thesis-based degree program. In this situation, a grade of PRU, Unsatisfactory Progress, may be given, and if given, indicates that a student has not made satisfactory progress toward the research component of a thesis-based degree program. In this case, receipt of a grade of PRU may trigger academic disciplinary proceedings as described in the Unsatisfactory Academic Performance (https://catalog.mines.edu/graduate/generalregulations/academicperformance/) portion of this Catalog.

Unless faculty submit the change of grade forms to the Registrar, grades of PRU delivered for unsatisfactory research performance, are not changed to PRG upon the successful completion of a student's degree program.

## NC Grade

For special reasons and with the instructor's permission, a student may register in a course for no credit (NC). To have the grade NC appear on the transcript, the student must enroll at registration time as an NC student in the course and comply with all conditions stipulated by the course instructor. If a student registered as NC fails to satisfy all conditions, no record of this registration in the course will be made.

## Quality Hours and Quality Points

For graduation, a student must successfully complete a certain number of required semester hours and must maintain grades at a satisfactory level. Numerical values assigned to each letter grade are given in the table below:

| Grade | Numerical Value |
|---|---|
| A | 4.000 |
| A- | 3.700 |
| B+ | 3.300 |
| B | 3.000 |
| B- | 2.700 |
| C+ | 2.300 |
| C | 2.000 |
| C- | 1.700 |
| D+ | 1.300 |
| D | 1.000 |
| D- | 0.700 |
| F | 0.000 |

The number of quality points earned in any course is the number of semester hours assigned to that course multiplied by the numerical value of the grade received. The quality hours earned are the number of semester hours in which grades are awarded. To compute a grade-point average, the number of cumulative quality hours is divided into the cumulative quality points earned. Grades of W, WI, INC, PRG, PRU, or NC are not counted in quality hours.

## Semester Hours

The number of times a class meets during a week (for lecture, recitation, or laboratory) determines the number of semester hours assigned to that course. Class sessions are normally 50 minutes long and represent one hour of credit for each hour meeting. A minimum of three hours of laboratory work per week is equivalent to 1-semester hour of credit. For the average student, each hour of lecture and recitation requires at least two hours of preparation.

## Grade-Point Averages

Grade-Point Averages shall be specified, recorded, reported, and used to three figures following the decimal point for any and all purposes to which said averages may apply.

All graduate degree programs require students to have a minimum overall grade point average of 3.000 in order to be eligible to receive the degree. All courses, including courses taken as a non-degree graduate student, undergraduate courses taken while a graduate student, deficiency courses and graduate level courses taken at the Colorado School of Mines after first enrolling in a graduate degree program are included in the calculation of the overall graduate grade point average. Grades for courses applied to a degree program as transfer credit are not included in any grade point average calculation. Specifics in calculating the overall, and other grade point averages are defined below.

## Overall Grade-Point Average

The overall graduate level grade-point average includes all attempts at courses taken at Colorado School of Mines while a graduate student, either degree seeking or non-degree graduate student, with the exception of courses completed when the repeat policy was in effect: Fall 2007 through Summer 2011.

If a course completed during the Fall 2007 term through Summer 2011 was a repeat of a course completed in any previous term and the course was not repeatable for credit, the grade and credit hours earned for the most recent occurrence of the course will count toward the student's grade-point average and the student's degree requirements. The most recent course occurrence must be an exact match to the previous course completed (subject and number). The most recent grade is applied to the overall grade-point average even if the previous grade is higher.

Courses from other institutions transferred to Colorado School of Mines are not counted in any grade-point average, and cannot be used under this repeat policy. Only courses originally completed and subsequently repeated at Colorado School of Mines during Fall 2007 through Summer 2011 with the same subject code and number apply to this repeat policy.

All occurrences of every course taken at Colorado School of Mines will appear on the official transcript along with the associated grade. Courses from other institutions transferred to Colorado School of Mines are not counted in any grade-point average.

## Course and Research Grades

All candidates for graduate degrees must maintain a cumulative grade point average of at least 3.0 in all courses taken at Mines and listed on the graduate transcript. This includes both graduate and undergraduate courses. Any grade lower than “C-” is not acceptable for credit toward graduate degree requirements.

For research credits, students receive either an “In Progress-Satisfactory” or an “In Progress-Unsatisfactory” grade based on their faculty advisor’s evaluation of their work. Research grades do not enter into the calculation of the student’s grade point average.

Students who fail to maintain a grade point average of at least 3.0, or who receive an In Progress-Unsatisfactory research grade are placed on academic probation by the Graduate Dean and may be subject to dismissal as defined by the Unsatisfactory Academic Performance (https://catalog.mines.edu/graduate/generalregulations/academicperformance/) section of this Catalog.

## GRADE CHANGES

After the completion of final grading for a term, only corrections to errors in grading may be processed and they must be for grade improvements only. Corrections to errors in grading for all students will be accepted one year from the original grade entry. With the exception of punitive disciplinary actions, diminution of a grade is not allowed without approval of the Provost.

## GRADE APPEAL PROCESS

Mines faculty have the responsibility, and sole authority for, assigning grades. As instructors, this responsibility includes clearly stating the instructional objectives of a course, defining how grades will be assigned in a way that is consistent with these objectives, and then assigning grades. It is the student's responsibility to understand the grading criteria and then maintain the standards of academic performance established for each course in which he or she is enrolled.

If a student believes he or she has been unfairly graded, the student may appeal this decision first to the instructor of the course, and if the appeal is denied, to the Academic Standards Committee of the Faculty Senate. The Academic Standards Committee is the faculty body authorized to review and modify course grades, in appropriate circumstances. Any decision made by the Academic Standards Committee is final. In evaluating a grade appeal, the Academic Standards Committee will place the burden of proof on the student. For a grade to be revised by the Academic Standards Committee, the student must demonstrate that the grading decision was unfair by documenting that one or more of the following conditions applied:

1. The grading decision was based on something other than course performance, unless the grade was a result of penalty for academic dishonesty.
2. The grading decision was based on standards that were unreasonably different from those applied to other students in the same section of that course.
3. The grading decision was based on standards that differed substantially and unreasonably from those previously articulated by the instructor.

To appeal a grade, the student should proceed as follows:

1. The student should prepare an appeal of the grade received in the course. This appeal must define the basis for the appeal and must present all relevant evidence supporting the student's case.
2. After preparing the appeal, the student should deliver this appeal to the course instructor and attempt to resolve the issue directly with the instructor. Written grade appeals must be delivered to the instructor no later than 10 business days after the start of the regular (fall or spring) semester immediately following the semester in which the contested grade was received. In the event that the course instructor is unavailable because of leave, illness, sabbatical, retirement, or resignation from the university, the course coordinator (first) or the Department Head/Division Director (second) shall represent the instructor.
3. If after discussion with the instructor, the student is still dissatisfied, he or she can proceed with the appeal by emailing a copy of the appeal and a copy of a summary of the instructor/student meetings held in connection with the previous step to the Academic Standards Committee. All information must be submitted to the committee no later than 25 business days after the start of the semester immediately following the semester in which the contested grade was received.
4. On the basis of all information deemed pertinent to the grade appeal, the Academic Standards Committee will determine whether the grade should be revised. The decision rendered will be either:
    a. the original grading decision is upheld, or
    b. sufficient evidence exists to indicate a grade has been assigned unfairly.

In the latter case, the Academic Standards Committee will assign the student a new grade for the course. The Committee's decision is final. The decision and supporting documentation will be delivered to the Faculty Senate, the office of the Executive Vice President for Academic Affairs, the student, the instructor, and the instructor's Department Head/ Division Director no later than 25 business days following the Faculty Senate's receipt of the grade appeal.

The schedule, but not the process, outlined above may be modified upon mutual agreement of the student, the course instructor, and the Academic Standards Committee.

# Graduation

## All students expecting to graduate must apply to graduate in Trailhead.

Graduation application deadlines are scheduled well in advance of the date of Commencement to allow time for commencement preparation. Students who submit applications after the stated deadline cannot be guaranteed a diploma dated for that graduation, and cannot be assured inclusion in the graduation program or ceremony. Graduation applications are accepted only for students who have previously submitted to, and had approved by the Office of Graduate Studies, the appropriate Advisor/Thesis Committee (thesis students only), Degree Audit form (all students), and Admission to Candidacy form (PhD candidates only) as applicable to the degree sought. Students earning more than one degree must submit the appropriate forms for each degree and apply to graduate for each degree.

## Graduation Requirements

**Registration**

To graduate, students must be registered during the term in which they complete their program. An exception to this registration policy allows students to complete an early checkout by census day of the graduation semester. Early checkout is accepted by the Graduate School and allows students to graduate in a term, without registering:

- checkout by Summer I census to graduate in August or December and avoid summer & fall registration,
- checkout by Fall census to graduate in December and avoid fall registration, and
- checkout by Spring census to graduate in May and avoid spring registration.

Students not meeting this checkout deadline are required to register for an additional semester before the Graduate School will process their checkout request. For additional information, refer to https://www.mines.edu/graduate-studies/graduation-deadlines/.

**Check-out**

All graduating students must officially check out of their degree program. Students will be enrolled in a Graduation Check-Out course after the student has applied to graduate in Trailhead.  Students must follow the directions and complete the course by the established deadline. Students must register for the graduation term, unless the checkout process is completed by census day of the graduation term.

**Awarding Degrees**

The awarding of a degree is contingent upon the student's successful completion of all program requirements with at least a 3.000 cumulative GPA before the date of graduation. Students who fail to graduate at the time originally anticipated must reapply for the next graduation before the appropriate deadline date stated on the Graduate School website.

Students who have completed all of their degree requirements by the early check-out deadline or at least 4 weeks prior to the standard check-out deadline can, if necessary, request a letter from the Graduate Office certifying the completion of their programs. The student must have applied to graduate for the current or next graduation, met all the degree requirements and have no holds. Degrees are not awarded during the early check-out time-frame, so for any student who is checking out early, the diploma and transcripts will show the date of the actual graduation and the degree will not show as being awarded until after degrees have been awarded for that term.

- December Early Check-Out in August/September: Degrees awarded in December/January
- May Early Check-Out in December/January: Degrees awarded in May
- August Early Check-Out in May: Degrees awarded in August/September

Degrees for all students, including those who check-out early, will be awarded within 10 business days after the commencement ceremony of the term in which the student applied to graduate, or for August graduates, 10 business days after the last day of the full summer term.

**Commencement**

Commencements are held in December and May. Students graduating in August may walk in the December graduation ceremony. Students eligible to graduate at these times are expected to attend their respective graduation exercises and must apply to graduate by the stated deadlines to be eligible to walk in the appropriate commencement ceremony. Students who do not apply to graduate by the stated deadlines, may not be allowed to walk in the commencement ceremony. The exception is non-thesis students graduating in August, may be allowed to walk in the May ceremony if all of the following are met: the student has less than 6 credits to complete in the summer, the student has applied to graduate in May and the student has consulted with the Mines Event Planner about the exception. Students in thesis-based degree programs may not, under any circumstances, attend graduation exercises before completing all degree requirements.

**Diplomas, Certificates, Transcripts and Letters of Completion**

Diplomas, certificates, transcripts, and letters of completion will not be released by the School for any student or graduate who has an unsettled obligation of any kind to the School. Diplomas and transcripts will be available through the Registrar's Office after degrees have been awarded. Students who check-out early may request a Letter of Completion from the Registrar's Office, but these letters will only be sent if requested at least 4 weeks prior to the commencement ceremony. Requests for a Letter of Completion after that time will not be accepted, so students will need to order the diploma or transcripts, as needed.

## Late Fee for Application to Graduate after Stated Deadlines - $75

The deadline to apply to graduate and participate in commencement is Census Day of the term in which the student intends to graduate/participate.

Any request to be added to the graduation list and/or commencement ceremony after Census Day and at least 5 weeks prior to the commencement ceremony for the appropriate semester, may be made in writing and will be considered by the Office of Graduate Studies. If the request is denied, the student will be required to apply for the next available graduation/ceremony. If the request is approved and all other conditions are met (i.e., degree requirements can be met, required forms are turned in, and outstanding hour limitations are not exceeded), a mandatory $75 fee will be applied to the student's account. This fee cannot be waived and cannot be refunded if the student does not meet the graduation check-out deadlines.

No graduate student will be added to a graduation or commencement when the request is made within less than 5 weeks to the commencement ceremony.

# Independent Studies

To register for an independent study course, a student must get the appropriate form from the Registrar's Office (https://www.mines.edu/registrar/forms/), have it completed by the instructor involved and appropriate department/division head, and return it to the Registrar's Office. The form must be submitted no later than the Census Day (last day of registration) for the term in which the independent study is to be completed.

For each semester credit hour awarded for independent study (x99 course), a student is expected to invest approximately 25.0 contact hours plus 30.0 hours of independent work. Additionally, the faculty certifies that an appropriate course syllabus has been developed for the course, reviewed by the Department/Division and the student, and is available upon request from the department.

| Credit Hours | Instructor Contact Hours | Independent Work Hours | Total Hours | Hours Per Week |
|---|---|---|---|---|
| 1.0 | 25.0 | 30.0 | 55.0 | 3.7 |
| 2.0 | 50.0 | 60.0 | 110.0 | 7.3 |
| 3.0 | 75.0 | 90.0 | 165.0 | 11.0 |
| 4.0 | 100.0 | 120.0 | 220.0 | 14.7 |
| 5.0 | 125.0 | 150.0 | 275.0 | 18.3 |
| 6.0 | 150.0 | 180.0 | 330.0 | 22.0 |

# Non-Degree Students

A non-degree student is one who has not applied to pursue a degree program at Mines but wishes to take courses regularly offered on campus. Non-degree students register for courses through the Registrar's Office after degree-seeking students have registered. Such students may take any course for which they have the prerequisites as listed in the Mines Catalog or have the permission of the instructor. Transcripts or evidence of the prerequisites are required. Non-degree students pay all applicable tuition and student fees. Non-degree students are not eligible for financial aid.

Courses completed while the student is a non-degree graduate student count toward the overall graduate-level grade point average on the Mines transcript.

For more information, please visit the Non-Degree Graduate website (https://www.mines.edu/graduate-admissions/non-degree/).

# Public Access to Graduate Thesis

The award of a thesis-based graduate degree is conditioned on the student uploading his or her completed thesis in the Electronic Thesis and Dissertation system to ensure its availability to the public. Although the student retains the copyright in the thesis, by uploading the thesis in the electronic system, the student assigns a perpetual, non-exclusive, royalty-free license to Mines to permit Mines to copy the thesis and allow the public reasonable access to it.

Under special circumstances, Mines may agree to include proprietary research in a graduate student's thesis. The nature and extent of the proprietary research reported in the thesis must be agreed upon in writing by the principal investigator and the student, and must be specified when the thesis or dissertation is uploaded into the electronic system.

In some cases, the proprietary nature of the underlying research may require the school to delay public access to the completed thesis for a limited period of time. In no case will public access to the thesis be denied for more than 12 months from the date the thesis or dissertation is published by the electronic system.

# Unsatisfactory Academic Performance

## Unsatisfactory Academic Progress Resulting in Probation or Discretionary Dismissal

A student's progress toward successful completion of a graduate degree shall be deemed unsatisfactory if any of the following conditions occur:

- Failure to maintain a cumulative grade point average of 3.0 or greater (see Graduate Grading System section);
- Receipt of an "Unsatisfactory Progress" grade for research; or
- Receipt of an "Unsatisfactory Progress" recommendation from the following:
  - the head or director of the student's home department or division,
  - the student's thesis committee, or
  - a departmental committee charged with the responsibility of monitoring the student's progress.

Unsatisfactory academic progress on the part of a graduate student shall be reported to the Graduate Dean in a timely manner. Students making unsatisfactory progress by any of the measures listed above are subject to discretionary dismissal according to the procedure outlined below.

In addition, students in thesis-based degree programs who are not admitted to candidacy within the time limits specified in this Catalog may be subject to immediate mandatory dismissal according to the procedure outlined below. Failure to fulfill this requirement must be reported to the Graduate Dean in a timely manner by the department head or division/program director.

## Probation and Discretionary Dismissal Process and Procedure

**Probation**

The first semester on academic probation, the student will be notified by the Graduate Dean and asked to consult with his/her advisor. The notation on the student's transcripts will indicate that the student is on probation. To have the probation notation removed from the transcripts, the student must address the issue that caused the academic probation (i.e. bring GPA to a 3.0 or above, not receive a PRU, or address the issue from the department) within one semester. Students who do not address the issue after one semester will have the academic probation notation remain on the transcripts.

**Discretionary Dismissal**

The second semester on academic probation (not necessarily a consecutive semester) will result in discretionary dismissal. The Graduate Dean will notify the student in a timely manner and invite him or her to submit a written remedial plan, including performance milestones and deadlines, to correct the deficiencies that caused or contributed to the student's unsatisfactory academic progress. The remedial plan, which must be approved by the student's faculty advisor and the department head, division or program director, shall be submitted to the Dean no later than 10 business days from the date of official notification to the student of the potential discretionary dismissal. If the Dean concludes that the remedial plan is likely to lead to successful completion of all degree requirements within an acceptable time frame, the Dean may halt the discretionary dismissal process and allow the student to continue working toward his or her degree. If the Dean concludes that the remedial plan is inadequate, or that it is unlikely to lead to successful completion of all degree requirements within an acceptable time frame, the Dean shall notify the student of his or her discretionary dismissal and inform the student of his or her right to appeal the dismissal as outlined below. Students who have a second semester on academic probation will have the academic probation notation remain on the transcripts for the remainder of the academic career.

If the student fails to meet the conditions of the remedial plan, the student will be subject to mandatory dismissal.

## Unsatisfactory Academic Performance Resulting in Mandatory Dismissal

Unsatisfactory performance as gauged by any of the following measures shall result in immediate, mandatory dismissal of a graduate student:

1. Failure to successfully defend the thesis after two attempts;
2. Failure to be admitted to candidacy; or
3. Failure by a student subject to discretionary dismissal to achieve a performance milestone or meet a deadline contained in his or her remedial plan.

The Graduate Dean shall be notified promptly of any situation that may subject a student to mandatory dismissal. In this event, the Dean shall notify the student of his or her dismissal and inform the student of his or her right to appeal the dismissal as outlined below.

Students who have been notified of mandatory dismissal will have 10 business days to appeal for extenuating circumstances or withdraw from school.

Students who have an appeal for extenuating circumstances approved by the faculty committee will be reinstated in the same degree program and will be allowed to continue with his/her studies as a graduate student. If an appeal is denied, the dismissal will stand.

Students who withdraw or are dismissed, may request re-admission to either the same program or a different degree program by submitting a full application for admission to Graduate Admissions. The application will be reviewed through the normal admission process. To return, the student will need to be re-admitted into a degree program.

If a student who has been reinstated or readmitted to his or her former degree program is subsequently found to be making unsatisfactory progress, the student will immediately be subject to mandatory dismissal.

## Appeal Procedures

Both mandatory and discretionary dismissals may be appealed by a graduate student pursuant to this procedure. To trigger review hereunder, an appeal must:

1. Be based on extenuating circumstances and/or irregularities in process. Examples of extenuating circumstances and/or irregularities in process along with suggested documentation and details can be found on the Graduate Student Dismissal Appeal form on the Office of Graduate Studies website.
2. Be submitted using the Graduate Student Dismissal Appeal form.
3. Include a description of the matter being appealed, supporting documentation, and a plan for successful completion of the degree program.
4. Be filed with the Office of Graduate Studies, c/o the Graduate Dean, no later than 10 business days from the date upon which the student

received official notification from the Dean regarding his or her dismissal.

Upon receipt of a timely appeal of a discretionary or mandatory dismissal, the Graduate Dean will review the stated grounds for the appeal. If the Dean determines that the appeal satisfies the conditions required for review, the Dean will request that the Faculty Senate appoint a review committee comprised of three tenured faculty members who are not members of the student's home or minor (if applicable) department or division. The review committee shall review the student's appeal and issue a written recommendation thereon to the Dean within 10 business days. During the course of performing this function, the committee may:

1. Interview the student, the student's advisor, and if appropriate, the student's thesis committee;
2. Review all documentation related to the appeal under consideration;
3. Secure the assistance of outside expertise, if needed; and
4. Obtain any other relevant information necessary to properly consider the appeal.

If the Dean determines that the appeal submitted does not have the required documentation showing sufficient extenuating circumstances, then the appeal will not be accepted and the student's dismissal will stand.

The authority to render a final decision regarding all graduate student appeals filed hereunder shall rest with the Graduate Dean.

# Exceptions and Appeals

## Academic Policies and Requirements

Academic policies and requirements are included in the Catalog on the authority of the Mines Board of Trustees as delegated to the Faculty Senate. These include matters such as degree requirements, grading systems, thesis and dissertation standards, admission standards, new and modified degree programs, certificates, minors and courses. No Mines administrator, faculty or staff member may change, waive or grant exceptions to such academic policies and requirements without approval of the Graduate Council, the Senate and/or the Board of Trustees as appropriate.

## Administrative Policies and Procedures

Administrative Policies and Procedures are included in this Catalog on the authority of the Mines Board of Trustees as delegated to the appropriate administrative office. These include (but are not limited to) matters such as student record keeping, thesis and dissertation formats and deadlines, registration requirements and procedures, assessment of tuition and fees, and allocation of financial aid. The Graduate Dean may waive or grant exceptions to such administrative policies and procedures as warranted by the circumstances of individual cases.

Any graduate student may request a waiver or exception by the following process:

1. Contact the Office of Graduate Studies to determine whether a standard form exists. If so, complete the form. If a standard form does not exist, prepare a memo with a statement of the request and a discussion of the reasons why a waiver or exception would be justified.
2. Have the memo or the form approved by the student's advisor and department head or division director, then submit it to the Graduate Dean.
3. If the request involves academic policies or requirements, the Graduate Dean will request Graduate Council approval at the Council's next regularly scheduled meeting.
4. The Graduate Dean will notify the student of the decision. The student may file a written appeal with the Provost within 10 business days of being notified of the decision. The Provost will investigate as appropriate to the issue under consideration and render a decision. The decision of the Provost is final.
5. At the next graduate Council meeting, the Dean will notify the Graduate Council of the request, the decision and the reasons for the decision. If the Graduate Council endorses the decision, then any other student in the same situation having the same justification can expect the same decision.

# Tuition, Fees, Financial Assistance

Tuition and fees are established by the Board of Trustees of Colorado School of Mines following the annual budget process and action by the Colorado General Assembly and Governor.

## Tuition

The official tuition and approved charges for the academic year will be available prior to the start of the academic year and can be found online on the Bursar's website (https://www.mines.edu/bursar/).

## Fees

The official fees, approved charges, and fee descriptions for the academic year will be available prior to the start of the academic year and can be found online on the Bursar's website (https://www.mines.edu/bursar/).

## Payments and Refunds

## Financial Responsibility

It is the student's responsibility to abide by Mines payment and refund policies when registering for classes.

- Full payment of tuition and fees are due by 4pm MST on the first business day following Census Day for each term. Please see the Bursar's website (https://www.mines.edu/bursar/) for specific semester information.
- Students are responsible for viewing their account balance online through Trailhead. Mines generates electronic invoices only, no paper invoices will be mailed.
- Students are responsible for dropping their courses by the published drop deadline if they don't plan to attend. Failure to do so will result in charges incurred on the student account.

## If you don't fulfill your financial obligations:

- Any unpaid balance at 4pm MST on the due date will be assessed a 1.5% late fee.
- An additional 1.5% late fee will be assessed to any unpaid balance each month thereafter.
- Accounts not paid in full by the last day to drop classes are considered past due. Holds will be placed on past due accounts preventing registration, transcripts, diplomas, and access to other student records.
- Accounts not paid in full at the end of each semester are considered delinquent. Delinquent accounts will be turned over to a collections agency in accordance with Colorado law and all collection fees and costs will be added to the account balance. The collection agency may report delinquent accounts to the national credit bureau.
- Students whose accounts have been sent to a collection agency must pay their balance in full <u>and</u> prepay for any subsequent semester before registration will be allowed.
- Any students whose debt to Mines was written off due to a bankruptcy discharge will be required to prepay for future semesters before registration will be allowed.

## Refunds

The amount of tuition and fee assessments is based primarily on each student's enrolled courses. In the event a student withdraws from a course or courses, assessments will be adjusted as follows:

- If withdrawal from a course or courses is made prior to the end of the add/drop period for the term of enrollment, as determined by the Registrar, tuition and fees will be adjusted to the new course level without penalty.
- If withdrawal from a course or courses is made after the add/drop period, regardless of whether or not the student officially withdraws from Mines, no adjustments in charges will be made.

Please note: students receiving federal financial aid under the Title IV programs may have a different refund as required by federal law or regulations.

Room and board refunds are pro-rated to the date of checkout from the Residence Hall. Arrangements must be made with the Housing Office.

Student health insurance charges are not refundable. The insurance remains in effect for the entire semester.

## Financial Assistance for Graduate Studies

Graduate study is a considerable investment of time, energy, and money by serious students who expect a substantial return not only in satisfaction but also in future earnings. Applicants are expected to weigh carefully the investment they are willing to make against expected benefits before applying for admission.

Students are also expected to make full use of any resources available, including personal and loan funds, to cover expenses, and the School can offer some students financial aid through graduate research and teaching assistantships and through the industry, state, and federal fellowships.

## Purpose of Financial Aid

The Graduate School's limited financial aid is used

1. To give equal access to graduate study by assisting students with limited personal resources;
2. To compensate graduate students who teach and do research;
3. To give an incentive to exceptional students who can provide academic leadership for continually improving graduate programs.

## Employment Restrictions and Agreements

Students who are employed full time or who are enrolled part-time are not eligible for financial aid through the Graduate School.

Students who are awarded assistant-ships must sign an appointment agreement, which gives the terms of appointment and specifies the amount and type of work required. Graduate assistants who hold regular appointments are expected to devote all of their efforts to their educational program and may not be otherwise employed without the written permission of their supervisor and the Graduate Dean. Students with assistantships during the academic year must be registered as full time. During the summer session, they must be registered for a minimum of three credit hours, unless they qualify for the summer research registration exception. Please see http://www.mines.edu/graduate_admissions (http://www.mines.edu/graduate_admissions/) for details on summer registration exception eligibility.

## Aid Application Forms

New students interested in applying for financial aid are encouraged to apply early. Financial aid forms are included in Graduate School application packets and may be filled out and returned with the other application papers.

## Graduate Fellowships

The departments and divisions may award fellowships based on the student's academic performance.

## Graduate Student Loans

Federal student loans are available for graduate students who need additional funding beyond their own resources and any assistantships or fellowships they may receive. The Free Application for Federal Student Aid (FAFSA) must be completed to apply for these loan funds. Students must be degree-seeking, taking courses towards their degree and attending at least part-time (4.5 hrs) per semester (including summer) to be eligible. Degree-seeking students who are approved for reduced registration (4 hrs/semester fall and spring and 3 hrs summer) are also eligible.

Specific information and procedures for filing the FAFSA can be found on the Financial Aid Office web site at http://finaid.mines.edu. The Financial Aid Office telephone number is 303-273-3301, and the email address is finaid@mines.edu.

## Satisfactory Academic Progress for Federal Student Loans and Colorado Grad Grant

Students receiving assistance from federal or Colorado funds must make satisfactory academic progress toward their degree. Satisfactory progress is defined by maintaining adequate pace towards graduation and maintaining a 3.0 cumulative GPA at all times. The pace is measured by dividing the overall credit hours attempted by the overall credit hours completed. Students will be required to maintain a 75% completion rate at all times. Satisfactory standing is determined after each semester, including summer. If students are deficient in either the pace or grade average measure, they will receive a one-semester warning period during which they must return to satisfactory standing.

If this is not done, their eligibility will be terminated until such time as they return to satisfactory standing. In addition, if students receive grades of F, PRU or INC in all of their courses, their future financial aid eligibility will be terminated without a warning period. Financial aid eligibility termination may be appealed to the Financial Aid Office on the basis of extenuating or special circumstances having negatively affected the student's academic performance. If approved, the student will receive a probationary period of one semester to regain satisfactory standing.

Late Fee for Application to Graduate after Stated Deadlines - $75

The deadline to apply to graduate and participate in commencement is Census Day of the term in which the student intends to graduate/participate.

Any request to be added to the graduation list and/or commencement ceremony after Census Day and at least 5 weeks prior to commencement ceremony of the appropriate semester, may be made in writing and will be considered by the Office of Graduate Studies.

If the request is denied, the student will be required to apply for the next available graduation/ceremony. If the request is approved and all other conditions are met (i.e. degree requirements can be met, required forms are turned in, and outstanding hour limitations are not exceeded), a mandatory $75 fee will be applied to the student's account. This fee cannot be waived and cannot be refunded if the student does not meet the graduation check-out deadlines.

No graduate student will be added to graduation or commencement when the request is made within less than 5 weeks to the commencement ceremony.

# Graduate Departments and Programs

Colorado School of Mines offers post-baccalaureate programs leading to the awarding of Post-Baccalaureate Certificates, Professional Master's degrees, thesis and non-thesis Master of Science degrees, non-thesis Master of Engineering degrees, and Doctor of Philosophy degrees. This section describes these degrees and explains the minimum institutional requirements for each. Students may apply to, and be admitted in, multiple graduate degrees simultaneously. In this case, a student may use the same graduate course credits to satisfy the degree requirements for each degree.

Students enrolled simultaneously and/or sequentially in two Mines Master's degree programs may use up to half of the course credits required for the Master's degree program with the smallest course credit hour requirement toward both degree programs. Before the Office of Graduate Studies will count these credits toward each degree requirement, the student must obtain written permission to do so from each department, division or program granting degree. This permission should be submitted with the student’s Degree Audit form and should clearly indicate that each degree program is aware that the specific credits are being counted toward the requirements of multiple master’s degrees. For thesis-based students this permission should be provided by the student’s thesis committee and department head, or division/ program director. For non-thesis and certificate programs, permission should be obtained from advisors and department head or division/ program director.

Students simultaneously and/or sequentially enrolled in a Master's degree and Doctoral degree may, with departmental approval, count course credits toward each degree without limit. Approval to count credits towards a Master’s degree and Doctoral degree will be indicated by the committee’s and department head's or division/program director's signature on the Degree Audit form.

Course credits may never be applied toward more than three graduate degrees.

## I. Responsible Conduct of Research Requirement

All students supported at any time in their graduate career through the National Science Foundation (NSF), as research assistants, hourly employees or fellowship awardees, must complete training in the responsible conduct of research (RCR). This requirement is in addition to all other institutional and program requirements described below and in the appropriate program sections of this Catalog.

To satisfy the RCR requirement students must complete one of the following options:

- HASS565- Option available to all students
- SYGN502 - Option available to all students
- Chemistry Program Option - Option available only to students in the Chemistry program
- Physics Program Option: Option available only to students with physics faculty advisors or co-advisors
- Chemical & Biological Engineering (CBE) Option - Option available only to students in the CBE degree program

For additional information on program-specific options, contact the program.

By whatever means chosen, the NSF-RCR requirement must be completed prior to a candidate submitting the Degree Audit form. Students and advisors certify successful completion of the RCR requirement on the Degree Audit form.

## II. Professional Programs

### A. Post-Baccalaureate Certificate Program

Post-Baccalaureate Certificate Programs at Mines are designed to have selective focus, short time to completion and consist of course work only. For more information about specific professional programs, please refer to the “Graduate Degree Programs and Description of Courses” portion of this Catalog.

**1. Academic Requirements**

Each Post-Baccalaureate Certificate requires a minimum of 9 total credit hours. Specific minimum credit-hour requirements are detailed within the “Graduate Degree Programs and Description of Courses” portion of this Catalog. Students may not, on an individual basis, request credit hours be transferred from other institutions as part of the Certificate requirements. Some Certificates, however, may allow the application of specific, pre-approved transfer credits, or credits from other institutions with whom Mines has formal agreements for this purpose toward fulfilling the requirements of the Certificate. All courses applied to a Post-Baccalaureate Certificate are subject to approval by the program offering the certificate.

If a student has earned a Post-Baccalaureate Certificate and subsequently applies, and is accepted into a Master's or PhD program at Mines, credits earned in the Certificate Program may, with the approval of the advanced degree program, be applied to the advanced degree subject to all the applicable restrictions on credit hours that may be applied toward fulfilling the requirements of the advanced degree.

**2. Graduation Requirements**

Full-time students must complete the following requirement within the first semester after enrolling into a Post-Baccalaureate Certificate degree program.

- complete all prerequisites and core curriculum course requirements of their program.

A list of prerequisites and core curriculum requirements for Post-Baccalaureate Certificates, if required, will be published by each program. If a student is admitted with deficiencies, the appropriate department head, division director or program director will provide the student with a written list of courses required to remove these deficiencies. This list will be given to the student no later than one week after the start of classes of his/her first semester in order to allow for adding/dropping courses as necessary.

Upon completion of the above-defined requirements, a student must apply to graduate in Trailhead and complete the Graduation Check-Out course by the posted deadlines.

## B. Professional Master's Program

Mines awards specialized, career-oriented non-thesis Master's degrees with the title of “Professional Master (descriptive title).” These are custom-designed, interdisciplinary degrees, each with a curriculum meeting the career advancement needs of a particular group of professionals in a field that is part of Mines' role and mission. For more information about these programs, please refer to the “Graduate Degree Programs and Description of Courses” portion of this Catalog.

**1. Academic Requirements**

Each Professional Master's degree consists of a minimum of 30 total credit hours. Students must complete at least 21 credit hours at Mines in the degree program. The remaining hours may be transferred into the program. Requests for transfer credit must be approved by the faculty according to a process defined by the student’s home department, division, or program. Transfer credits must not have been used as credit toward a Bachelor's degree. The transfer limit includes Mines distance learning courses. Up to six credit hours of Special Topic or Independent Study may be in the form of project credits done on the job as an employee or as a graduate intern. If project credits are to be used, the project proposal and final report must be approved by a Mines faculty advisor, although direct supervision may be provided by the employer. Students must maintain a cumulative grade point average of 3.0 or better in Mines course work.

**2. Graduation Requirements**

Full-time students must complete the following requirement within the first calendar year after enrolling into a Professional Master's degree program.

- complete all prerequisite and core curriculum course requirements of their program.

If students are admitted with deficiencies, the appropriate department heads, or division/program directors will provide the students written lists of courses required to remove the deficiencies. These lists will be given to the students no later than one week after the start of classes of their first semester in order to allow them to add/drop courses as necessary. Completion of prerequisites and deficiencies will be monitored by the department.

Upon completion of the above defined requirements, students must submit a Degree Audit form documenting satisfactory completion of the core curriculum requirements. Deficiency and/or prerequisite courses may not be listed on the Degree Audit form. The form must have the written approval of all members of the advisor and thesis committee, if appropriate.

To graduate, all Professional Master students must submit all required forms, apply to graduate in Trailhead, and complete the Graduation Check-Out course by the posted deadlines.

# III. Master of Science and Master of Engineering Programs

## A. General Requirements

Graduate study at Mines can lead to one of a number of thesis and non-thesis based Master’s degrees, depending on the interests of the student. All Master’s degree programs share the same academic requirements for grades and definition of minor programs.

**1. Academic Requirements**

A Master’s degree at Mines requires a minimum of 30 total credit hours, with some degrees requiring additional credits. As part of this minimum 30 hours, departments and divisions are required to include a research or design experience supervised by Mines faculty. For more information about the specific research/design requirements, please refer to the appropriate department/division section of the “Graduate Degree Programs and Description of Courses” portion of this Catalog.

For non-thesis Master's degrees, students must complete at least 21 credit hours at Mines in the degree program. All other coursework credits may be completed as transfer credits into the degree program. For thesis Master's degrees, no more than 9 coursework credits may transfer.

The transfer credit limit includes any credits listed on a Mine’s undergraduate transcript and/or any credits taken at another university, including credits taken under the Exchange Reciprocal Agreement. Transfer credits must not have been used as credit toward a Bachelor's degree, must not be pre-requisites or deficiencies, must have a letter grade of C or better, must be graduate level credits and must be required for the degree. Requests for transfer credit must be approved by the faculty according to the process defined by a student's home department or division. All credits applied toward degree, except transfer credits, must be earned on campus. Students must maintain a cumulative grade point average of 3.0 or better in Mines course work.

**2. Minor Programs**

Students may choose to have a minor program or programs at the Master’s level. A minor program may not be taken in the student’s major area of study. A designated minor requires a minimum of 9 semester hours of graduate course work and must be approved by the student’s advisor, home department head/division director, and a graduate faculty representative of the minor area of study. Less than half of the credit hours applied toward the minor degree program may be in the form of transfer credit hours. Transfer credit hours applied toward the minor are included as part of the overall transfer limitation applied to the degree as defined above.

**3. Graduation Requirements**

Full-time students must complete the following requirements within one calendar year of enrolling into the Master’s degree program.

- have a thesis committee appointment form on file in the Office of Graduate Studies (thesis based students only), and
- complete all prerequisite and core curriculum course requirements of their department, division or program.

If students are admitted with deficiencies, the appropriate department heads, division directors or program directors will provide the students written lists of courses required to remove the deficiencies. These lists will be given to the students no later than one week after the start of classes of their first semester in order to allow them to add/drop courses as necessary. Completion of prerequisites and deficiencies will be monitored by the department.

Upon completion of the above defined requirements, students must submit a Degree Audit form documenting satisfactory completion of the core curriculum requirements.* Deficiency and/or prerequisite courses may not be listed on the Degree Audit form. The form must have the written approval of all members of the advisor and thesis committee, if appropriate.

* Depending on the admit term, some students may not need to submit a Degree Audit form. Students who do not need to submit a Degree Audit form will be notified the first semester of study. Students who do not need to submit a Degree Audit form will however need to submit a form to transfer credits, double count credits and/or substitute courses.

To graduate, all Master of Science and Master of Engineering students must submit all forms, apply to graduate in Trailhead, and complete the Graduation Check-Out by the posted deadlines. In addition, thesis-based students must submit a signed Thesis Defense Form, upload a content-approved thesis and have the formatting approved by the posted deadlines.

## B. Non-thesis Option

Non-thesis Master's degrees (both non-thesis Master of Science and Master of Engineering) are offered by a number of departments, divisions and programs. In lieu of preparing a thesis, non-thesis master's program students are required to complete a research or design experience taken as a special problem or as an independent study course. See the department/division section of the "Graduate Degree Programs and Description of Courses" portion of this Catalog for more information. Although non-thesis master's students are not assigned a Thesis Committee, students in this program are assigned a faculty advisor by the student's home department. The advisor is subject to approval by the Office of Graduate Studies.

## C. Thesis Option

Thesis-based Master of Science degrees require completion of a satisfactory thesis and successful oral defense of this thesis. Academic credit toward completion of the thesis must include successful completion of no fewer than 6 credit hours of masters-level research credit. The thesis is expected to report on original research that results in new knowledge and/or techniques or on creative engineering design that applies state-of-the-art knowledge and techniques to solve an important problem. In either case, the thesis should be an exemplary product that meets the rigorous scholarship standards of the Colorado School of Mines. The student's faculty advisor and the Master's Thesis Committee must approve the program of study and the topic for the thesis. The format of the thesis must comply with the appropriate guidelines promulgated by the Office of Graduate Studies.

**1. Faculty Advisor Appointment**

When admitted, each thesis-based Master's student is assigned a faculty advisor by the department. Students who are assigned temporary advisors at admissions will work with their department to have a permanent advisor assigned. Master's students changing a temporary advisor to a permanent advisor or selecting a new advisor will need the new faculty advisor approved by the Office of Graduate Studies by the end of the second semester at Mines.

Advisors will provide advice regarding the student's thesis direction, research and selection of courses. To be approved by the Office of Graduate Studies, advisors must be designated as Mines Graduate Faculty. Please refer to the Faculty Handbook for a definition of what constitutes Mines Graduate Faculty. Upon approval by the Graduate Dean, adjunct faculty, teaching faculty, visiting professors, emeritus professors and off-campus representatives may be designated additional co-advisors.

The Director of the degree program, often times the head of the student's home department or division, and the Graduate Dean must approve all faculty advisor appointments.

**2. Thesis Committee**

The Graduate Dean will approve a Thesis Committee whose members have been recommended by the student, the student's faculty advisor, the student's department head and whose members meet the minimum requirements listed below. Students should have a thesis committee approved by the end of their second semester.

This Committee will have a minimum of three voting members, including the student's advisor, who are familiar with the student's area of study.

1. Of these three (3) Committee members, the first member will be the student's advisor. The advisor must be Graduate Faculty.
2. The 2nd member must be designated as Mines Graduate Faculty, Teaching Faculty, Professor of Practice, Research Faculty, External Joint Appointee or Emeritus Faculty from the home department or, in the case of interdisciplinary degree programs, designated as Mines faculty in any of the categories above in the interdisciplinary program.
3. The 3rd member of the committee may be Mines faculty (any category of Mines faculty) or an off campus member.
    - Off-campus members can be assigned to the Committee as the 3rd member or as additional members. If assigned as the 3rd member, the member must be a voting member. Off-campus members nominated for voting status on the committee request form must include a brief resume of their education and/or experience that demonstrates their competence to judge the quality and validity of the thesis. Such members also must agree to assume the same responsibilities expected of on-campus Committee members including, but not limited to, attendance at Committee meetings, review of thesis proposals and drafts and defense.
4. Additional members (more than the 3 required), either Mines faculty or off campus members may serve either with full voting status or in a non-voting capacity. Off-campus members with voting status assume all of the responsibilities of on-campus Committee members with respect to attendance of Committee meetings, review of thesis drafts, participation in oral examinations and thesis defense sessions.
5. If a thesis co-advisor is assigned, an additional member, Mines faculty or off campus member, must be added to the committee. Co-advisors must be voting members of the committee.
6. Students who choose to have a minor program at the Master's level must select a representative from their minor department of study to serve on the Thesis Committee. Minor representatives must be a designated as a Mines Graduate Faculty or Teaching Faculty member in the Minor department.
7. A Thesis Committee Chairperson is designated by the student at the time he/she requests the formation of his/her thesis committee. The chairperson is responsible for leading all meetings of the thesis committee and for directing the student's thesis defense. In selecting a Thesis Committee chairperson, the following guidelines must be met:
    - The chairperson cannot be the student's advisor or co-advisor and
    - The chairperson must be a designated as a Mines graduate faculty member.

Shortly after its appointment, the Committee will meet with the student to hear a presentation of the proposed course of study and thesis topic. The Committee and the student must agree on a satisfactory program and the student must obtain the Committee approval of the written thesis proposal at least one semester prior to the thesis defense. The student's faculty advisor assumes the primary responsibility for monitoring the program and directing the thesis work. The award of the thesis-based Master's degree is contingent upon the student's researching and writing a thesis acceptable to the student's faculty advisor and Thesis Committee.

**3. Thesis Defense**

The student submits an initial draft of his or her thesis to the faculty advisor, who will work with the student on necessary revisions. Upon approval of the student's advisor, the revised thesis is circulated to the Thesis Committee members at least one week prior to the oral defense of the thesis. The oral defense of the thesis is scheduled during the student's final semester of study. Students must be registered to defend. This defense session, which may include an examination of material covered in the student's course work, will be open to the public.

Following the defense, the Thesis Committee will meet privately to vote on whether the student has successfully defended the thesis. Three outcomes are possible: the student may pass the oral defense; the student may fail the defense; or the Committee may vote to adjourn the defense to allow the student more time to address and remove weaknesses or inadequacies in the thesis or underlying research. Two negative votes will constitute a failure regardless of the number of Committee members present at the thesis defense. In the event of either failure or adjournment, the Chair of the Thesis Committee will prepare a written statement indicating the reasons for this action and will distribute copies to the student, the Thesis Committee members, the student's department head and the Graduate Dean. In the case of failure or adjournment, the student may request a re-examination, which must be scheduled no less than one week after the original defense. A second failure to defend the thesis satisfactorily will result in the termination of the student's graduate program.

Upon passing the oral defense of thesis or report, the student must make any corrections in the thesis required by the Thesis Committee. The final, corrected copy and an executed signature page indicating approval by the student's advisor and department head must be submitted to the Registrar's Office for format approval. (Format instructions are available on the Office of Graduate Studies website and should be thoroughly read before beginning work on the thesis.)

**4. Time Limitations**

A candidate for a thesis-based Master's degree must complete all requirements for the degree within five years of the date of admission into the degree program. Time spent on approved leaves of absence is included in the five-year time limit. Candidates not meeting the time limitation will be notified and withdrawn from their degree programs.

Candidates may apply for a one-time extension of this time limitation. This application must be made in writing and approved by the candidate's advisor, thesis committee, department and Graduate Dean. The application must include specific timelines and milestones for degree completion. If an extension is approved, failure to meet any timeline or milestone will trigger immediate withdrawal from the degree program.

If the Graduate Dean denies an extension request, the candidate may appeal this decision to the Provost. The appeal must be made in writing, must specifically state how the candidate believes the request submitted to the Dean met the requirements of the policy, and must be received no later than 10 business days from the date of notification of the Dean's denial of the original request.

If a candidate is withdrawn from a degree program through this process (i.e., either by denial of an extension request or failure to meet a timeline or milestone) and wishes to re-enter the degree program, that candidate must formally reapply for readmission. The program has full authority to determine if readmission is to be granted and, if granted, to fully re-evaluate the Candidate's work to date and determine its applicability to the new degree program.

# IV. Doctor of Philosophy

## A. Credits, Hour and Academic Requirements

The Doctor of Philosophy degree requires completion of a minimum of 72 semester hours beyond the Bachelor degree. At least 24 semester hours must be research credits earned under the supervision of a Mines faculty advisor and at least 18 credit hours of course work must be applied to the degree program. Course requirements for each department or division are contained in the "Graduate Degree Programs and Description of Courses" section of this Catalog.

The degree also requires completion of a satisfactory doctoral thesis and successful oral defense of this thesis. The Doctoral Thesis is expected to report on original research that results in a significant contribution of new knowledge and/or techniques. The student's faculty advisor and the Doctoral Thesis Committee must approve the program of study and the topic for the thesis.

## B. Residency Requirements

Doctoral students must complete a residency requirement during the course of their graduate studies. The purpose of this requirement is as follows:

- require students to become engaged in extended and focused research activities under the direct supervision of Mines faculty;
- allow students to become immersed in the culture of an academic environment;
- allow students to engage in the professional activities associated with their research discipline;
- ensure students have access to the research tools and expertise needed for their chosen research activity;
- ensure the conduct of cutting-edge research with the expectation that this research will be completed in a timely fashion so that it is still relevant to the larger research community;
- provide Mines faculty with the ability to directly evaluate the research and academic credentials of a student and as such protect the integrity of the degree, department and the institution;
- ensure the research produced by students claiming a Mines degree is actually the product of Mines' intellectual environment; and
- make it clear that the intellectual property developed while in the degree program is the property of Mines as defined in the Faculty Handbook.

The residency requirement may be met by completing two semesters of full-time registration at Mines. The semesters need not be consecutive. Students may request an exception to the full-time registration requirement from the Graduate Dean. Requests for exception must be in writing, must clearly address how the student's learning experience has met the goals of the residency requirement, as articulated above, and must be submitted by both the student and the student's thesis advisor and be approved by the student's Department Head/Division Director.

Students in online doctoral programs are exempt from this residency requirement.

## C. Transfer of Credits

Up to 24 semester hours of graduate-level course work may be transferred from other institutions toward the PhD degree subject to the restriction that those courses must not have been used as credit toward a Bachelor degree, must not be prerequisites or deficiencies, must have a letter grade of C or better and must be graduate level credits. Requests for transfer credit must be approved by the faculty according to a process defined by the student’s home department or division. Transfer credits are not included in calculating the student’s grade point average at Mines.

In lieu of transfer credit for individual courses defined above, students who enter the PhD program with a thesis-based Master’s degree from another institution may transfer up to 36 semester hours in recognition of the course work and research completed for that degree. The request must be approved by the faculty according to a process defined by the student’s home department or division.

## D. Faculty Advisor Appointments

When admitted, each doctoral student is assigned a Graduate Faculty advisor by the department. Students who are assigned temporary advisors at admissions will work with their department to have a permanent advisor assigned. PhD students changing a temporary advisor to a permanent advisor or selecting a new advisor will need the new faculty advisor approved by the Office of Graduate Studies by the end of the second semester at Mines.

Advisors will advise students with respect to the student’s thesis direction, research and selection of courses. Advisors must be designated as a Mines graduate faculty member. Please refer to the Faculty Handbook for a definition of what constitutes Mines graduate faculty. Upon approval by the Graduate Dean, adjunct faculty, teaching faculty, visiting professors, emeritus professors and off-campus representatives may be designated additional co-advisors.

The Director of the doctoral degree program, often times the head of the student's home department or division, and the Graduate Dean must approve all faculty advisor appointments.

## E. Minor Programs

Students may choose a minor program or programs at the PhD level consisting of 12 course credits in the minor program. The student's faculty advisor and Doctoral Thesis Committee, including an appropriate minor committee member as described below, approve the course selection and sequence in the selected minor program. Students may choose to complete multiple minor programs. Each program must consist of at least 12 credit hours approved by the faculty advisor and Doctoral Thesis Committee, including the appropriate minor committee members. Less than half of the credit hours applied toward the minor degree program may be in the form of transfer credit hours. Transfer credit hours applied toward a minor are included as part of the overall transfer limitation applied to the degree as defined above.

## F. Doctoral Thesis Committees

The Graduate Dean will approve a Doctoral Thesis Committee whose members have been recommended by the student, the student’s faculty advisor, the student’s department head and whose members meet the minimum requirements listed below. Students should have a thesis committee approved by the end of their second year of study. This Committee must have a minimum of four voting members that fulfill the following criteria:

1. The Committee must include an advisor who must be classified as Graduate Faculty and must meet the qualifications defined above. If two advisors are appointed, advisor and co-advisor, both shall be voting members of the Committee.
2. The Committee must have at least two voting members knowledgeable in the technical areas of the thesis in addition to the advisor(s) and who are designated as either Mines Graduate Faculty, Teaching Faculty, Professor of Practice, Research Faculty or Emeritus Faculty.
3. The fourth, required member of the Committee must be designated as a Mines Graduate Faculty, Teaching Faculty or Professor of Practice. The $4^{th}$ member may not be an advisor, co-advisor, or minor representative, and must be from outside of the student's doctoral, home department and minor program area(s) – if appropriate. This committee member acts as Thesis Committee Chairperson.
4. If a thesis co-advisor is assigned, an additional member, Mines faculty or off campus member, must be added to the committee. Co-advisors must be voting members of the committee.
5. If a minor field is designated, an additional committee member must be included who is an expert in that field. Minor representatives must be designated as Mines graduate faculty members who are participating faculty in the minor program area. If multiple minor programs are pursued, each must have a committee representative as defined above.
6. Off-campus representatives may serve as additional committee members. If off-campus members are nominated for voting status, the committee request form must include a brief resume of their education and/or experience that demonstrates their competence to judge the quality and validity of the thesis. Such members also must agree to assume the same responsibilities expected of on-campus Committee members including, but not limited to, attendance at Committee meetings, review of thesis proposals and drafts, and participation in oral examinations and defense.

Shortly after its appointment, the Doctoral Thesis Committee meets with the student to hear a presentation of the proposed course of study and thesis topic. The Committee and student must agree on a satisfactory program. The student’s faculty advisor then assumes the primary responsibility for monitoring the program, directing the thesis work, arranging qualifying examinations, and scheduling the thesis defense.

Upon completion of all prerequisite and core curriculum course requirements of their department division or program, students must submit a Degree Audit form documenting satisfactory completion of the core curriculum requirements. Deficiency and/or prerequisite courses may not be listed on the Degree Audit form. The form must have the written approval of all members of the advisor and thesis committee, if appropriate.

## G. Admission to Candidacy

Full-time students must complete the following requirements within the first two calendar years after enrolling into the PhD program.

- have an approved thesis committee form on file;
- complete all prerequisite and core curriculum course requirements of their department, division or program;
- demonstrate adequate preparation for, and satisfactory ability to conduct, doctoral research; and
- be admitted into full candidacy for the degree.

If students are admitted with deficiencies, the appropriate department heads, division directors or program directors will provide the students written lists of courses required to remove the deficiencies. These lists will be given to the students no later than one week after the start of classes of their first semester in order to allow them to add/drop courses as necessary. Completion of prerequisites and deficiencies will be monitored by the department.

Each program also defines the process for determining whether its students have demonstrated adequate preparation for, and have satisfactory ability to do, high-quality, independent doctoral research in their specialties. These requirements and processes are described under the appropriate program headings in the section of this Catalog on Graduate Degree Programs and Description of Courses.

To graduate, all PhD students must submit all required paperwork, apply to graduate in Trailhead, complete the Graduation Check-Out course, complete the Survey of Earned Doctorate and submit the signed Thesis Defense Form by the posted deadlines. In addition, PhD students must upload a content approved thesis and have the formatting approved by the posted check-out deadlines.

## H. Thesis Defense

The doctoral thesis must be based on original research of excellent quality in a suitable technical field, and it must exhibit satisfactory literary merit. In addition, the format of the thesis must comply with guidelines promulgated by the Office of Graduate Studies. (Formatting requirements are listed on the Office of Graduate Studies website and students should thoroughly read these guidelines before beginning work on the thesis.)

The thesis topic must be submitted in the form of a written proposal to the student's faculty advisor and the Committee. The Committee must approve the proposal at least one year before the thesis defense.

The student's faculty advisor is responsible for supervising the student's research work and consulting with other Doctoral Thesis Committee members on the progress of the work. The advisor must consult with the Committee on any significant change in the nature of the work. The student submits an initial draft of his or her thesis to the advisor, who will work with the student on necessary revisions. Upon approval of the student's advisor, the revised thesis is distributed to the other members of the Committee at least one week prior to the oral defense of the thesis.

The student must pass an oral defense of his or her thesis during the final semester of studies. Students must be registered to defend. This oral defense may include an examination of material covered in the student's course work. The defense will be open to the public.

Following the defense, the Doctoral Thesis Committee will meet privately to vote on whether the student has successfully defended the thesis. Three outcomes are possible: the student may pass the oral defense; the student may fail the defense; or the Committee may vote to adjourn the defense to allow the student more time to address and remove weaknesses or inadequacies in the thesis or underlying research. Two negative votes will constitute a failure regardless of the number of Committee members present at the thesis defense. In the event of either failure or adjournment, the Chair of the Doctoral Thesis Committee will prepare a written statement indicating the reasons for this action and will distribute copies to the student, the Thesis Committee members, the student's department head and the Graduate Dean. In the case of failure, the student may request a re-examination, which must be scheduled no less than one week after the original defense. A second failure to defend the thesis satisfactorily will result in the termination of the student's graduate program.

Upon passing the oral defense of thesis, the student must make any corrections in the thesis required by the Doctoral Thesis Committee. The final, corrected copy and an executed signature page indicating approval by the student's advisor and department head must be submitted to the Registrar's Office for format approval.

## I. Time Limitations

A candidate for a thesis-based Doctoral degree must complete all requirements for the degree within nine years of the date of admission into the degree program. Time spent on approved leaves of absence is included in the nine-year time limit. Candidates not meeting the time limitation will be notified and withdrawn from their degree programs.

Candidates may apply for a one-time extension of this time limitation. This application must be made in writing and approved by the candidate's advisor, thesis committee, department and Graduate Dean. The application must include specific timelines and milestones for degree completion. If an extension is approved, failure to meet any timeline or milestone will trigger immediate withdrawal from the degree program.

If the Graduate Dean denies an extension request, the candidate may appeal this decision to the Provost. The appeal must be made in writing, must specifically state how the candidate believes the request submitted to the Dean met the requirements of the policy, and must be received no later than 10 business days from the date of notification of the Dean's denial of the original request. The Provost's decision is final.

If a candidate is withdrawn from a degree program through this process (i.e., either by denial of an extension request or failure to meet a timeline or milestone) and wishes to reenter the degree program, that candidate must formally reapply for readmission. The program has full authority to determine if readmission is to be granted, and if granted, to fully re-evaluate the Candidate's work to date and determine its applicability to the new degree program.

# V. Roles and Responsibilities of Committee Members and Students

Below are the roles and expectations Mines has of faculty as members of Thesis Committees and of students engaged in research-based degree programs.

## Thesis Advisor(s)

The Thesis Advisor has the overall responsibility for guiding the student through the process of the successful completion of a thesis that fulfills the expectations of scholarly work at the appropriate level as well as meets the requirements of the Department/Division and the School. The Advisor shall:

- be able and willing to assume principal responsibility for advising the student;
- have adequate time for this work and be accessible to the student;
- provide adequate and timely feedback to both the student and the Committee regarding student progress toward degree completion;
- guide and provide continuing feedback on the student's development of a research project by providing input on the intellectual appropriateness of the proposed activities, the reasonableness of project scope, acquisition of necessary resources and expertise, necessary laboratory or computer facilities, etc.;
- establish key academic milestones and communicate these to the student and appropriately evaluate the student on meeting these milestones.

## Regular Committee Member

With the exception of the student's advisor, all voting members of the Thesis Committee are considered Regular Committee Members. The Regular Committee Member shall:

- have adequate time to assume the responsibilities associated with serving on a student's Thesis Committee;
- be accessible to the student (at a minimum this implies availability for Committee meetings and availability to participate in a student's qualifying/comprehensive examinations – as dictated by the practices employed by the degree program – and the thesis defense);
- ensure that the student's work conforms to the highest standards of scholarly performance within the discipline and within the expertise provided by the Committee member;
- provide advice to both the student and the student's advisor(s) on the quality, suitability and timeliness of the work being undertaken;
- approve the student's degree plan (e.g., courses of study, compliance with program's qualifying process, thesis proposal, etc.), assuring that the plan not only meets the intellectual needs of the student, but also all institutional and program requirements;
- review dissertation drafts as provided by the student and the advisor and provide feedback in a timely fashion; and
- participate in, and independently evaluate student performance in the final thesis defense.

## Minor Field Committee Representative

In addition to the responsibilities of a Regular Committee Member, the Minor Field Committee Representative has the following added responsibilities:

- provide advice for and approval of coursework required as part of a student's minor degree program in a manner that is consistent with institutional and minor program requirements;
- participate in, as appropriate, the student's qualifying and comprehensive examination process to certify completion of minor degree requirements; and
- work individually with the student on the thesis aspects for which the Minor Committee member has expertise.

## Thesis Committee Chairperson

In addition to the responsibilities of a Regular Committee Member, the Chairperson of Committee has the following added responsibilities:

- chair all meetings of the Thesis Committee including the thesis defense;
- represent the broad interests of the Institution with respect to high standards of scholarly performance;
- represent the Office of Graduate Studies by ensuring that all procedures are carried out fairly and in accordance with institutional guidelines and policies; and

- ensure that any potential conflicts of interest between student, advisor or any other committee member are effectively identified and managed.

## Student Responsibilities

While it is expected that students receive guidance and support from their advisor and all members of the Thesis Committee, the student is responsible for actually defining and carrying out the program approved by the Thesis Committee and completing the thesis/dissertation. As such, it is expected that the student assumes a leadership role in defining and carrying out all aspects of his/her degree program and thesis/dissertation project. Within this context, students have the following responsibilities:

- to formally establish a Thesis Advisor and Committee by the end of their first year of residence in their degree program;
- to call meetings of the Thesis Committee as needed;
- to actively inform and solicit feedback from the student's Advisor and Committee on progress made toward degree;
- to respond to, and act on feedback from the student's Advisor and Committee in a timely and constructive manner;
- to understand and then apply the institutional and programmatic standards related to the ethical conduct of research in the completion of the student's thesis/dissertation; and
- to know, understand and follow deadlines defined by the institution and the degree program related to all aspects of the student's degree program.

# VI. Combined Undergraduate/Graduate Degree Programs

## A. Overview

Many degree programs offer Mines undergraduate students the opportunity to begin work on a Graduate Certificate, Professional Master’s Degree, Master’s Degree, or Doctoral Degree while completing the requirements for their Bachelor’s Degree. These combined Bachelors-Master's/Doctoral programs have been created by Mines faculty in those situations where they have deemed it academically advantageous to treat undergraduate and graduate degree programs as a continuous and integrated process. These are accelerated programs that can be valuable in fields of engineering and applied science where advanced education in technology and/or management provides the opportunity to be on a fast track for advancement to leadership positions. These programs also can be valuable for students who want to get a head start on graduate education.

The combined programs at Mines offer several advantages to students who choose to enroll in them:

1. Students can earn a graduate degree in their undergraduate major or in a field that complements their undergraduate major.
2. Students who plan to go directly into industry leave Mines with additional specialized knowledge and skills which may allow them to

enter their career path at a higher level and advance more rapidly. Alternatively, students planning on attending graduate school can get a head start on their graduate education.

3. Students can plan their undergraduate electives to satisfy prerequisites, thus ensuring adequate preparation for their graduate program.
4. Early assignment of graduate advisors permits students to plan optimum course selection and scheduling in order to complete their graduate program quickly.
5. Early acceptance into a Combined Degree Program leading to a Graduate Degree assures students of automatic acceptance into full graduate status if they maintain good standing while in early-acceptance status.
6. In many cases, students will be able to complete both a Bachelor's and a Master's Degrees in five years of total enrollment at Mines.

Certain graduate programs may allow Combined Degree Program students to fulfill part of the requirements of their graduate degree by including up to six hours of specified course credits which also were used in fulfilling the requirements of their undergraduate degree. These courses, referred to as double counted courses, may be applied toward fulfilling a Doctoral degree and many Master's degree requirements. Check the departmental section of the Catalog to determine which programs provide this opportunity and any limitations that might apply.

Double counted courses must:

- Meet all requirements for graduate credit, but their grades are not included in calculating the graduate GPA.
  - Some degree programs only allow students to double count 500 level courses (not 400 level), so please check the degree program for details.
- Must have a grade of B- or better (as listed on the undergraduate transcript).

Some degree programs have stricter limitations, so please check the degree program for details.

## B. Admission Process

A student interested in applying into a graduate degree program as a Combined Degree Program student should first contact the department or division hosting the graduate degree program into which he/she wishes to apply. Initial inquiries may be made at any time, but initial contacts made soon after completion of the first semester, Sophomore year are recommended. Following this initial inquiry, departments/divisions will provide initial counseling on degree application procedures, admissions standards and degree completion requirements.

Admission into a graduate degree program as a Combined Degree Program student can occur as early as the first semester, Junior year, and must be granted no later than the end of registration, last semester Senior year. Once admitted into a graduate degree program, students may enroll in 500-level courses and apply these directly to their graduate degree. To apply, students must submit the standard graduate application packet for the graduate portion of their Combined Degree Program. Upon admission into a graduate degree program, students are assigned graduate advisors. Prior to registration for the next semester, students and their graduate advisors should meet and plan a strategy for completing both the undergraduate and graduate programs as efficiently as possible. Until their undergraduate degree requirements are completed, students continue to have undergraduate advisors in the home department or division of their Bachelor's Degrees.

## C. Requirements

Combined Degree Program students are considered undergraduate students until such time as they complete their undergraduate degree requirements. Combined Degree Program students who are still considered undergraduates by this definition have all of the privileges and are subject to all expectations of both their undergraduate and graduate programs. These students may enroll in both undergraduate and graduate courses (see section D below), may have access to departmental assistance available through both programs, and may be eligible for undergraduate financial aid as determined by the Office of Financial Aid. Upon completion of their undergraduate degree requirements, a Combined Degree Program student is considered enrolled full-time in his/her graduate program. Once having done so, the student is no longer eligible for undergraduate financial aid, but may now be eligible for graduate financial aid. To complete their graduate degree, each Combined Degree Program student must register as a graduate student for at least one semester.

Once admitted into a graduate program, undergraduate Combined Program students must maintain good standing in the Combined Program by maintaining a minimum semester GPA of 3.0 in all courses taken. Students not meeting this requirement are deemed to be making unsatisfactory academic progress in the Combined Degree Program. Students for whom this is the case are subject to probation and, if occurring over two semesters, subject to discretionary dismissal from the graduate portion of their program as defined in the Unsatisfactory Academic Performance section of this Catalog.

Upon completion of the undergraduate degree requirements, Combined Degree Program students are subject to all requirements (e.g., course requirements, departmental approval of transfer credits, research credits, minimum GPA, etc.) appropriate to the graduate program in which they are enrolled.

## D. Enrolling in Graduate Courses as a Senior in a Combined Program

As described in the Undergraduate Catalog, seniors may enroll in 500-level courses. In addition, undergraduate seniors who have been granted admission through the Combined Degree Program into thesis-based degree programs (Master's or Doctoral) may, with graduate advisor approval, register for 700-level research credits appropriate to Master's-level degree programs. With this single exception, while a Combined Degree Program student is still completing his/her undergraduate degree, all of the conditions described in the Undergraduate Catalog for undergraduate enrollment in graduate-level courses apply. 700-level research credits are always applied to a student's graduate degree program.

If an undergraduate Combined Degree Program student would like to enroll in a 500-level course and apply this course directly to his/her graduate degree, he/she must submit the 500 Level Form to the Registrar's Office. On the form, the student will select the appropriate option for the course, use as undergraduate credit or use as graduate credit.

- Students who have been accepted into a graduate level program and have submitted the "intend to enroll" information by census day of the term in which the class is taken are eligible to have the credits listed on the graduate level transcripts. In this case, the grades will impact the graduate G.P.A. and the student may take an unlimited number of credits to use towards the graduate level degree. Students must remember that all students earning a graduate degree must register at least one semester as a graduate student.

- Students who have either not been admitted into a graduate program or those who have been admitted, but have not submitted the “intend to enroll” by census day of the term in which the class is taken, are not eligible to have the credits listed on the graduate level transcripts, even if the student does not need the credits for the undergraduate degree. In this case, the credits will be listed on the undergraduate level transcripts and the grades will impact the undergraduate G.P.A. If these credits are not used towards an undergraduate degree requirement, they may with departmental approval, be applied to a graduate program as transfer credits. All regular regulations and limitations regarding the use of transfer credit to a graduate degree program apply to these credits.

The Registrar will forward the registration information to Financial Aid for appropriate action. Be aware that courses taken as an undergraduate student but not used toward a bachelor's degree are not eligible for undergraduate financial aid or the Colorado Opportunity Fund.

# Applied Mathematics & Statistics

## Degrees Offered

- Master of Science (Applied Mathematics and Statistics)
- Doctor of Philosophy (Applied Mathematics and Statistics)

## Program Description

The Department of Applied Mathematics and Statistics (AMS) offers two graduate degrees: A Master of Science in Applied Mathematics and Statistics and a Doctor of Philosophy in Applied Mathematics and Statistics. The master's program is designed to prepare candidates for careers in industry or government or for further study at the PhD level. The PhD program is sufficiently flexible to prepare candidates for careers in industry, government and academia. A course of study leading to the PhD degree can be designed either for students who have completed a Master of Science degree or for students with a Bachelor of Science degree.

The AMS department is also intertwined into the curriculum of three different interdisciplinary master's degrees including Data Science, Operations Research with Engineering, and Quantitative Biosciences and Engineering. Please view the "Interdisciplinary Programs" for more information on these programs.

Research within AMS is conducted in the following areas:

**Computational and Applied Mathematics**
Study of Wave Phenomena and Inverse Problems
Numerical Methods for PDEs
Study of Differential and Integral Equations
Computational Radiation Transport
Computational Acoustics and Electromagnetics
Multi-scale Analysis and Simulation
High Performance Scientific Computing
Dynamical Systems
Mathematical Biology
Meshfree Approximation Methods

**Statistics**
Inverse Problems in Statistics
Multivariate Statistics
Spatial Statistics
Stochastic Models for Environmental Science
Survival Analysis
Uncertainty Quantification
Computational and Environmental Statistics

## Master of Science Program Requirements

The Master of Science degree (non-thesis option) requires 30 credit hours of coursework. Students pursuing the degree may count up to six credits from courses at the 400-level. For both the Computational & Applied Mathematics and Statistics specialties, the curriculum structure consists of (i) a set of required courses, (ii) a pair of MATH electives, and (iii) general elective courses that serve to supplement the student's technical interests.

## *Specialty in Computational & Applied Mathematics*

*Required Courses*

| | | |
|---|---|---|
| MATH500 | LINEAR VECTOR SPACES | 3.0 |
| MATH501 | APPLIED ANALYSIS | 3.0 |
| MATH514 | APPLIED MATHEMATICS I | 3.0 |
| MATH515 | APPLIED MATHEMATICS II | 3.0 |
| MATH550 | NUMERICAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS | 3.0 |
| MATH551 | COMPUTATIONAL LINEAR ALGEBRA | 3.0 |
| SYGN502 | INTRODUCTION TO RESEARCH ETHICS * | 1.0 |
| MATH589 | APPLIED MATHEMATICS AND STATISTICS TEACHING SEMINAR ** | 1.0 |

*Required only for students receiving federal support.
** Required only for students employed by the department as graduate teaching assistants or student instructor/lecturers.

Furthermore, students are required to complete two additional MATH courses, either at the 500-level or chosen from the following 400-level courses.

### *MATH Elective Courses (400-level)*

| | | |
|---|---|---|
| MATH408 | COMPUTATIONAL METHODS FOR DIFFERENTIAL EQUATIONS | 3.0 |
| MATH454 | COMPLEX ANALYSIS | 3.0 |
| MATH455 | PARTIAL DIFFERENTIAL EQUATIONS | 3.0 |
| MATH458 | ABSTRACT ALGEBRA | 3.0 |
| MATH484 | MATHEMATICAL AND COMPUTATIONAL MODELING (CAPSTONE) | 4.0 |

Finally, the remaining six credits come from general elective courses and may be selected from any other graduate courses offered by the Department of Applied Mathematics and Statistics, except for specially designated service courses. Alternatively, up to 6 credits of elective courses may be taken in other departments on campus to satisfy this requirement.

## *Specialty in Statistics*

### *Required Courses*

| | | |
|---|---|---|
| MATH500 | LINEAR VECTOR SPACES | 3.0 |
| MATH530 | STATISTICAL METHODS I | 3.0 |
| MATH531 | STATISTICAL METHODS II | 3.0 |
| MATH534 | MATHEMATICAL STATISTICS I | 3.0 |
| MATH535 | MATHEMATICAL STATISTICS II | 3.0 |
| SYGN502 | INTRODUCTION TO RESEARCH ETHICS * | 1.0 |
| MATH589 | APPLIED MATHEMATICS AND STATISTICS TEACHING SEMINAR ** | 1.0 |

*Required only for students receiving federal support.
** Required only for students employed by the department as graduate teaching assistants or student instructor/lecturers.

Furthermore, students are required to complete two additional MATH courses, either at the 500-level or chosen from the following 400-level courses.

### *MATH Elective Courses (400-level)*

| | | |
|---|---|---|
| MATH408 | COMPUTATIONAL METHODS FOR DIFFERENTIAL EQUATIONS | 3.0 |
| MATH454 | COMPLEX ANALYSIS | 3.0 |

| | | |
|---|---|---|
| MATH455 | PARTIAL DIFFERENTIAL EQUATIONS | 3.0 |
| MATH458 | ABSTRACT ALGEBRA | 3.0 |
| MATH484 | MATHEMATICAL AND COMPUTATIONAL MODELING (CAPSTONE) | 3.0 |

Finally, the remaining nine credits come from general elective courses and may be selected from any other graduate courses offered by the Department of Applied Mathematics and Statistics, except for specially designated service courses. Alternatively, up to 6 credits of elective courses may be taken in other departments on campus to satisfy this requirement.

***The Master of Science degree (thesis option) requires 30 credit hours of acceptable coursework and research, completion of a satisfactory thesis, and successful oral defense of this thesis. Six of the 30 credit hours must be designated for supervised research. The coursework includes the required core curriculum for the chosen specialty described above.***

## Mines Combined Undergraduate / Graduate Degree Program

The Department of Applied Mathematics and Statistics offers a combined Bachelor of Science/Master of Science program that enables students to work on a Bachelor of Science and a Master of Science in either specialty simultaneously. Students take 30 credit hours of coursework at the graduate level in addition to the undergraduate requirements, and work on both degrees at the same time. As described above, students pursuing the Master of Science degree may count up to six credits from courses at the 400-level. Additionally, students enrolled within the combined program may choose up to six credits of MATH coursework at the 500-level (that has been successfully completed with a grade of B or above) to "double-count"; that is, apply towards both their Bachelor of Science degree requirements and their Master of Science degree requirements simultaneously. Interested students are encouraged to apply for the combined program once they have completed five classes with a MATH prefix numbered 225 or higher.

## Doctor of Philosophy Program Requirements

The Doctor of Philosophy requires 72 credit hours beyond the bachelor's degree. At least 24 of these hours must be thesis hours. Students pursuing the degree may count up to six credits from courses at the 400-level.  Doctoral students must pass the comprehensive examination (a qualifying examination and thesis proposal), complete a satisfactory thesis, and successfully defend their thesis.

## *Specialty in Computational & Applied Mathematics*

### *Required Courses*

| | | |
|---|---|---|
| MATH500 | LINEAR VECTOR SPACES | 3.0 |
| MATH501 | APPLIED ANALYSIS | 3.0 |
| MATH514 | APPLIED MATHEMATICS I | 3.0 |
| MATH515 | APPLIED MATHEMATICS II | 3.0 |
| MATH550 | NUMERICAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS | 3.0 |
| MATH551 | COMPUTATIONAL LINEAR ALGEBRA | 3.0 |
| SYGN502 | INTRODUCTION TO RESEARCH ETHICS * | 1.0 |
| MATH589 | APPLIED MATHEMATICS AND STATISTICS TEACHING SEMINAR ** | 1.0 |

*Required only for students receiving federal support.
** Required only for students employed by the department as graduate teaching assistants or student instructor/lecturers.

Furthermore, students are required to complete two additional MATH courses, either at the 500-level or chosen from the following 400-level courses.

### *MATH Elective Courses (400-level)*

| | | |
|---|---|---|
| MATH408 | COMPUTATIONAL METHODS FOR DIFFERENTIAL EQUATIONS | 3.0 |
| MATH454 | COMPLEX ANALYSIS | 3.0 |
| MATH455 | PARTIAL DIFFERENTIAL EQUATIONS | 3.0 |
| MATH458 | ABSTRACT ALGEBRA | 3.0 |
| MATH484 | MATHEMATICAL AND COMPUTATIONAL MODELING (CAPSTONE) | 3.0 |

## *Specialty in Statistics*

### *Required Courses*

| | | |
|---|---|---|
| MATH500 | LINEAR VECTOR SPACES | 3.0 |
| MATH530 | STATISTICAL METHODS I | 3.0 |
| MATH531 | STATISTICAL METHODS II | 3.0 |
| MATH534 | MATHEMATICAL STATISTICS I | 3.0 |
| MATH535 | MATHEMATICAL STATISTICS II | 3.0 |
| SYGN502 | INTRODUCTION TO RESEARCH ETHICS * | 1.0 |
| MATH589 | APPLIED MATHEMATICS AND STATISTICS TEACHING SEMINAR ** | 1.0 |

*Required only for students receiving federal support.
** Required only for students employed by the department as graduate teaching assistants or student instructor/lecturers.

Furthermore, students are required to complete two additional MATH courses, either at the 500-level or chosen from the following 400-level courses.

### *MATH Elective Courses (400-level)*

| | | |
|---|---|---|
| MATH408 | COMPUTATIONAL METHODS FOR DIFFERENTIAL EQUATIONS | 3.0 |
| MATH454 | COMPLEX ANALYSIS | 3.0 |
| MATH455 | PARTIAL DIFFERENTIAL EQUATIONS | 3.0 |
| MATH458 | ABSTRACT ALGEBRA | 3.0 |
| MATH484 | MATHEMATICAL AND COMPUTATIONAL MODELING (CAPSTONE) | 3.0 |

**Further information can be found on the Web at ams.mines.edu. This website provides an overview of the programs, requirements, and policies of the department.**

## Fields of Research

## Computational and Applied Mathematics:

Study of Wave Phenomena and Inverse Problems

Numerical Methods for PDEs

Study of Differential and Integral Equations

Computational Radiation Transport

Computational Acoustics and Electromagnetics

Multiscale Analysis and Simulation

High Performance Scientific Computing

Dynamical Systems

Mathematical Biology

## Statistics:

Inverse Problems in Statistics

Multivariate Statistics

Spatial Statistics

Machine Learning

Stochastic Models for Environmental Science

Survival Analysis

Uncertainty Quantification

## Courses

**MATH500. LINEAR VECTOR SPACES. 3.0 Semester Hrs.**
(I) Finite dimensional vector spaces and subspaces: dimension, dual bases, annihilators. Linear transformations, matrices, projections, change of basis, similarity. Determinants, eigenvalues, multiplicity. Jordan form. Inner products and inner product spaces with orthogonality and completeness. Prerequisite: MATH301, MATH332. 3 hours lecture; 3 semester hours.

**MATH501. APPLIED ANALYSIS. 3.0 Semester Hrs.**
(I) Fundamental theory and tools of applied analysis. Students in this course will be introduced to Banach, Hilbert, and Sobolev spaces; bounded and unbounded operators defined on such infinite dimensional spaces; and associated properties. These concepts will be applied to understand the properties of differential and integral operators occurring in mathematical models that govern various biological, physical and engineering processes. Prerequisites: MATH301 or equivalent. 3 hours lecture; 3 semester hours.

**MATH502. REAL AND ABSTRACT ANALYSIS. 3.0 Semester Hrs.**
(I) Normed space R, open and closed sets. Lebesgue measure, measurable sets and functions. Lebesgue integral and convergence theorems. Repeated integration and integration by substitution. Lp spaces, Banach and Hilbert spaces. Weak derivatives and Sobalev spaces. Weak solutions of two-point boundary value problems. Prerequisites: MATH301 or equivalent. 3 hours lecture; 3 semester hours.

**MATH503. FUNCTIONAL ANALYSIS. 3.0 Semester Hrs.**
(II) Properties of metric spaces, normed spaces and Banach spaces, inner product and Hilbert spaces. Fundamental theorems for normed and Banach spaces with applications. Orthogonality and orthonormal systems on Hilbert spaces with applications to approximation theory. Compact, bounded and unbounded operators. Duality, adjoint, self-adjoint, Hilbert-adjoint operators. Spectral analysis of linear operators. Applications to differential and integral equations. Prerequisites: MATH502. 3 hours lecture; 3 semester hours.

**MATH506. COMPLEX ANALYSIS II. 3.0 Semester Hrs.**
(II) Analytic functions. Conformal mapping and applications. Analytic continuation. Schlicht functions. Approximation theorems in the complex domain. Taught every other year. Prerequisite: MATH454. 3 hours lecture; 3 semester hours.

**MATH510. ORDINARY DIFFERENTIAL EQUATIONS AND DYNAMICAL SYSTEMS. 3.0 Semester Hrs.**
(I) Topics to be covered: basic existence and uniqueness theory, systems of equations, stability, differential inequalities, Poincare-Bendixon theory, linearization. Other topics from: Hamiltonian systems, periodic and almost periodic systems, integral manifolds, Lyapunov functions, bifurcations, homoclinic points and chaos theory. Offered even years. Prerequisite: (MATH225 or MATH235) and (MATH332 or MATH342). 3 hours lecture; 3 semester hours.

**MATH514. APPLIED MATHEMATICS I. 3.0 Semester Hrs.**
The major theme in this course is various non-numerical techniques for dealing with partial differential equations which arise in science and engineering problems. Topics include transform techniques, Green's functions and partial differential equations. Stress is on applications to boundary value problems and wave theory. Prerequisite: MATH455 or equivalent.

**MATH515. APPLIED MATHEMATICS II. 3.0 Semester Hrs.**
Topics include integral equations, applied complex variables, an introduction to asymptotics, linear spaces and the calculus of variations. Stress is on applications to boundary value problems and wave theory, with additional applications to engineering and physical problems. Prerequisite: MATH514.

**MATH530. STATISTICAL METHODS I. 3.0 Semester Hrs.**
(I) Introduction to probability, random variables, and discrete and continuous probability models. Elementary simulation. Data summarization and analysis. Confidence intervals and hypothesis testing for means and variances. Chi square tests. Distribution-free techniques and regression analysis. Prerequisite: MATH213 or equivalent.

**MATH531. STATISTICAL METHODS II. 3.0 Semester Hrs.**
(II) Continuation of MATH530. Multiple regression and trend surface analysis. Analysis of variance. Experimental design (Latin squares, factorial designs, confounding, fractional replication, etc.) Nonparametric analysis of variance. Topics selected from multivariate analysis, sequential analysis or time series analysis. Prerequisite: MATH201 or MATH530 or MATH535. 3 hours lecture; 3 semester hours.

**MATH532. SPATIAL STATISTICS. 3.0 Semester Hrs.**
(I) Modeling and analysis of data observed on a 2 or 3-dimensional surface. Random fields, variograms, covariances, stationarity, nonstationarity, kriging, simulation, Bayesian hierarchical models, spatial regression, SAR, CAR, QAR, and MA models, Geary/Moran indices, point processes, K-function, complete spatial randomness, homogeneous and inhomogeneous processes, marked point processes, spatio-temporal modeling. Course is offered every other year on even years. Prerequisites: MATH424 or MATH531. 3 hours lecture; 3 semester hours.

**MATH534. MATHEMATICAL STATISTICS I. 3.0 Semester Hrs.**
(I) The basics of probability, discrete and continuous probability distributions, sampling distributions, order statistics, convergence in probability and in distribution, and basic limit theorems, including the central limit theorem, are covered. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MATH535. MATHEMATICAL STATISTICS II. 3.0 Semester Hrs.**
(II) The basics of hypothesis testing using likelihood ratios, point and interval estimation, consistency, efficiency, sufficient statistics, and some nonparametric methods are presented. Prerequisite: MATH534 or equivalent. 3 hours lecture; 3 semester hours.

**MATH536. ADVANCED STATISTICAL MODELING. 3.0 Semester Hrs.**
(II) Modern extensions of the standard linear model for analyzing data. Topics include generalized linear models, generalized additive models, mixed effects models, and resampling methods. Offered every two years on odd years. 3 hours lecture; 3 semester hours. Prerequisite: MATH335, MATH424.

**MATH537. MULTIVARIATE ANALYSIS. 3.0 Semester Hrs.**
(II) Introduction to applied multivariate representations of data for use in data analysis. Topics include introduction to multivariate distributions; methods for data reduction, such as principal components; hierarchical and model-based clustering methods; factor analysis; canonical correlation analysis; multidimensional scaling; and multivariate hypothesis testing. Prerequisites: MATH 530 and MATH 332 or MATH 500. 3 hours lecture; 3.0 semester hours.

**MATH538. STOCHASTIC MODELS. 3.0 Semester Hrs.**
(II) An introduction to the mathematical principles of stochastic processes. Discrete- and continuous-time Markov processes, Poisson processes, Brownian motion. Offered every two years on even years. 3 hours lecture; 3 semester hours.

**MATH539. SURVIVAL ANALYSIS. 3.0 Semester Hrs.**
(I) Basic theory and practice of survival analysis. Topics include survival and hazard functions, censoring and truncation, parametric and non-parametric inference, the proportional hazards model, model diagnostics. Offered on odd years. Prerequisite: MATH335, MATH535. 3 hours lecture; 3 semester hours.

**MATH540. PARALLEL SCIENTIFIC COMPUTING. 3.0 Semester Hrs.**
(II) This course is designed to facilitate students? learning of parallel programming techniques to efficiently simulate various complex processes modeled by mathematical equations using multiple and multi-core processors. Emphasis will be placed on the implementation of various scientific computing algorithms in FORTRAN/C/C++ using MPI and OpenMP. Prerequisite: MATH307. 3 hours lecture; 3 semester hours.

**MATH542. SIMULATION. 3.0 Semester Hrs.**
(I) Advanced study of simulation techniques, random number, and variate generation. Monte Carlo techniques, simulation languages, simulation experimental design, variance reduction, and other methods of increasing efficiency, practice on actual problems. 3 hours lecture; 3 semester hours. Prerequisite: CSCI262 (or equivalent), MATH201 (or MATH 424 or MATH530 or equivalent).

**MATH544. ADVANCED COMPUTER GRAPHICS. 3.0 Semester Hrs.**
Equivalent with CSCI544,
This is an advanced computer graphics course in which students will learn a variety of mathematical and algorithmic techniques that can be used to solve fundamental problems in computer graphics. Topics include global illumination, GPU programming, geometry acquisition and processing, point based graphics and non-photorealistic rendering. Students will learn about modern rendering and geometric modeling techniques by reading and discussing research papers and implementing one or more of the algorithms described in the literature.

**MATH547. SCIENTIFIC VISUALIZATION. 3.0 Semester Hrs.**
Equivalent with CSCI547,
Scientific visualization uses computer graphics to create visual images which aid in understanding of complex, often massive numerical representation of scientific concepts or results. The main focus of this course is on techniques applicable to spatial data such as scalar, vector and tensor fields. Topics include volume rendering, texture based methods for vector and tensor field visualization, and scalar and vector field topology. Students will learn about modern visualization techniques by reading and discussing research papers and implementing one of the algorithms described in the literature.

**MATH550. NUMERICAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS. 3.0 Semester Hrs.**
(II) Numerical methods for solving partial differential equations. Explicit and implicit finite difference methods; stability, convergence, and consistency. Alternating direction implicit (ADI) methods. Weighted residual and finite element methods. Prerequisite: MATH225 or MATH235, and MATH332 or MATH342. 3 hours lecture; 3 semester hours.

**MATH551. COMPUTATIONAL LINEAR ALGEBRA. 3.0 Semester Hrs.**
(II) Numerical analysis of algorithms for solving linear systems of equations, least squares methods, the symmetric eigenproblem, singular value decomposition, conjugate gradient iteration. Modification of algorithms to fit the architecture. Error analysis, existing software packages. 3 hours lecture; 3 semester hours. Prerequisite: MATH332, MATH 307.

**MATH556. MODELING WITH SYMBOLIC SOFTWARE. 3.0 Semester Hrs.**
(I) Case studies of various models from mathematics, the sciences and engineering through the use of the symbolic software package MATHEMATICA. Based on hands-on projects dealing with contemporary topics such as number theory, discrete mathematics, complex analysis, special functions, classical and quantum mechanics, relativity, dynamical systems, chaos and fractals, solitons, wavelets, chemical reactions, population dynamics, pollution models, electrical circuits, signal processing, optimization, control theory, and industrial mathematics. The course is designed for graduate students and scientists interested in modeling and using symbolic software as a programming language and a research tool. It is taught in a computer laboratory. Prerequisites: none. 3 hours lecture; 3 semester hours.

**MATH557. INTEGRAL EQUATIONS. 3.0 Semester Hrs.**
(I) This is an introductory course on the theory and applications of integral equations. Abel, Fredholm and Volterra equations. Fredholm theory: small kernels, separable kernels, iteration, connections with linear algebra and Sturm-Liouville problems. Applications to boundary-value problems for Laplace's equation and other partial differential equations. Offered even years. Prerequisite: MATH332 or MATH342 and MATH455. 3 hours lecture; 3 semester hours.

**MATH559. ASYMPTOTICS. 3.0 Semester Hrs.**
Equivalent with MATH459,
(I) Exact methods for solving mathematical problems are not always available: approximate methods must be developed. Often, problems involve small parameters, and this can be exploited so as to derive approximations: these are known as asymptotic approximations. Many techniques for constructing asymptotic approximations have been devised. The course develops such approximations for algebraic problems, the evaluation of integrals, and the solutions of differential equations. Emphasis is placed on effective methods and, where possible, rigorous analysis. Prerequisites: Calculus and ordinary differential equations. 3 hours lecture; 3 semester hours.

**MATH560. INTRODUCTION TO KEY STATISTICAL LEARNING METHODS I. 3.0 Semester Hrs.**

Part one of a two-course series introducing statistical learning methods with a focus on conceptual understanding and practical applications. Methods covered will include Introduction to Statistical Learning, Linear Regression, Classification, Resampling Methods, Basis Expansions, Regularization, Model Assessment and Selection.

**MATH561. INTRODUCTION TO KEY STATISTICAL LEARNING METHODS II. 3.0 Semester Hrs.**

(I) Part two of a two course series introducing statistical learning methods with a focus on conceptual understanding and practical applications. Methods covered will include Non-linear Models, Tree-based Methods, Support Vector Machines, Neural Networks, Unsupervised Learning Prerequisite: MATH560.

**MATH572. MATHEMATICAL AND COMPUTATIONAL NEUROSCIENCE. 3.0 Semester Hrs.**

(II) This course will focus on mathematical and computational techniques applied to neuroscience. Topics will include nonlinear dynamics, hysteresis, the cable equation, and representative models such as Wilson-Cowan, Hodgkin-Huxley, and FitzHugh-Nagumo. Applications will be motivated by student interests. In addition to building basic skills in applied math, students will gain insight into how mathematical sciences can be used to model and solve problems in neuroscience; develop a variety of strategies (computational, theoretical, etc.) with which to approach novel mathematical situations; and hone skills for communicating mathematical ideas precisely and concisely in an interdisciplinary context. In addition, the strong computational component of this course will help students to develop computer programming skills and apply appropriate technological tools to solve mathematical problems. Prerequisite: MATH331. 3 hours lecture; 3 semester hours.

**MATH574. THEORY OF CRYPTOGRAPHY. 3.0 Semester Hrs.**

Equivalent with CSCI574,

Students will draw upon current research results to design, implement and analyze their own computer security or other related cryptography projects. The requisite mathematical background, including relevant aspects of number theory and mathematical statistics, will be covered in lecture. Students will be expected to review current literature from prominent researchers in cryptography and to present their findings to the class. Particular focus will be given to the application of various techniques to real-life situations. The course will also cover the following aspects of cryptography: symmetric and asymmetric encryption, computational number theory, quantum encryption, RSA and discrete log systems, SHA, steganography, chaotic and pseudo-random sequences, message authentication, digital signatures, key distribution and key management, and block ciphers. Prerequisites: CSCI262 plus undergraduate-level knowledge of statistics and discrete mathematics. 3 hours lecture, 3 semester hours.

**MATH582. STATISTICS PRACTICUM. 3.0 Semester Hrs.**

(II) This is the capstone course in the Statistics Option. The main objective is to apply statistical knowledge and skills to a data analysis problem, which will vary by semester. Students will gain experience in problem-solving; working in a team; presentation skills (both orally and written); and thinking independently. Prerequisites: MATH 201 or 530 and MATH 424 or 531. 3 hours lecture and discussion; 3 semester hours.

**MATH589. APPLIED MATHEMATICS AND STATISTICS TEACHING SEMINAR. 1.0 Semester Hr.**

(I) An introduction to teaching issues and techniques within the AMS department. Weekly, discussion-based seminars will cover practical issues such as lesson planning, grading, and test writing. Issues specific to the AMS core courses will be included. 1 hour lecture; 1.0 semester hour.

**MATH598. SPECIAL TOPICS. 6.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**MATH599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**

(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**MATH610. ADVANCED TOPICS IN DIFFERENTIAL EQUATIONS. 3.0 Semester Hrs.**

(II) Topics from current research in ordinary and/or partial differential equations; for example, dynamical systems, advanced asymptotic analysis, nonlinear wave propagation, solitons. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MATH614. ADVANCED TOPICS IN APPLIED MATHEMATICS. 3.0 Semester Hrs.**

(I) Topics from current literature in applied mathematics; for example, wavelets and their applications, calculus of variations, advanced applied functional analysis, control theory. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MATH616. INTRODUCTION TO MULTI-DIMENSIONAL SEISMIC INVERSION. 3.0 Semester Hrs.**

(II) Introduction to high frequency inversion techniques. Emphasis on the application of this theory to produce a reflector map of the earth?s interior and estimates of changes in earth parameters across those reflectors from data gathered in response to sources at the surface or in the interior of the earth. Extensions to elastic media are discussed, as well. Includes high frequency modeling of the propagation of acoustic and elastic waves. Prerequisites: partial differential equations, wave equation in the time or frequency domain, complex function theory, contour integration. Some knowledge of wave propagation: reflection, refraction, diffraction. 3 hours lecture; 3 semester hours.

**MATH650. ADVANCED TOPICS IN NUMERICAL ANALYSIS. 3.0 Semester Hrs.**

(II) Topics from the current literature in numerical analysis and/or computational mathematics; for example, advanced finite element method, sparse matrix algorithms, applications of approximation theory, software for initial value ODE's, numerical methods for integral equations. 3 hours lecture; 3 semester hours. Prerequisite: Consent of Instructor.

**MATH691. GRADUATE SEMINAR. 1.0 Semester Hr.**

(I) Presentation of latest research results by guest lecturers, staff, and advanced students. Prerequisite: none. 1 hour seminar; 1 semester hour. Repeatable for credit to a maximum of 12 hours.

**MATH692. GRADUATE SEMINAR. 1.0 Semester Hr.**
Equivalent with CSCI692,
(II) Presentation of latest research results by guest lecturers, staff, and advanced students. Prerequisite: none. 1 hour seminar; 1 semester hour. Repeatable for credit to a maximum of 12 hours.

**MATH693. WAVE PHENOMENA SEMINAR. 1.0 Semester Hr.**
(I, II) Students will probe a range of current methodologies and issues in seismic data processing, with emphasis on under lying assumptions, implications of these assumptions, and implications that would follow from use of alternative assumptions. Such analysis should provide seed topics for ongoing and subsequent research. Topic areas include: Statistics estimation and compensation, deconvolution, multiple suppression, suppression of other noises, wavelet estimation, imaging and inversion, extraction of stratigraphic and lithologic information, and correlation of surface and borehole seismic data with well log data. Prerequisite: none. 1 hour seminar; 1 semester hour.

**MATH698. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**MATH699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**MATH707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) GRADUATE THESIS/DISSERTATION RESEARCH CREDIT Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

## Department Head

Greg Fasshauer, Professor

## Professors

Bernard Bialecki

Mahadevan Ganesh

Paul A. Martin

William Navidi

Doug Nychka

## Associate Professor

Soutir Bandopadhyay

Dorit Hammerling

Stephen Pankavich

Jennifer Ryan

Luis Tenorio

## Assistant Professors

Cecilia Diniz Behn

Karin Leiderman

## Teaching Professors

Debra Carney

G. Gustave Greivel

Mike Nicholas

Scott Strong

Rebecca Swanson

## Teaching Associate Professors

Terry Bridgman

Holly Eklund

Mike Mikucki

Ashlyn Munson

Jennifer Strong

## Emeriti Professors

William R. Astle

Norman Bleistein

Ardel J. Boes

Austin R. Brown

John A. DeSanto

Graeme Fairweather

Raymond R. Gutzman

Frank G. Hagin

Willy Hereman

Donald C.B. Marsh

Steven Pruess

## Emeriti Associate Professors

Barbara B. Bath

Ruth Maurer

# Chemical and Biological Engineering

## Degrees Offered

- Master of Science (Chemical Engineering)
- Doctor of Philosophy (Chemical Engineering)

## Program Description

The Chemical and Biological Engineering Department of the Colorado School of Mines is a dynamic, exciting environment for research and higher education. Mines provides a rigorous educational experience where faculty and top-notch students work together on meaningful research with far-reaching societal applications. Departmental research areas include bioengineering, catalysis, colloids and complex fluids, computational science, fuel cells, gas hydrates, membranes, polymers, and solar and electronic materials. Visit our website for additional information about our graduate program. http://chemeng.mines.edu/

## Program Requirements

## Prerequisites

The program outlined here assumes that the candidate for an advanced degree has a background in chemistry, mathematics, and physics equivalent to that required for the BS degree in Chemical Engineering at the Colorado School of Mines. Undergraduate course deficiencies must be removed prior to enrollment in graduate coursework.

The essential undergraduate courses include:

| | | |
|---|---|---|
| CBEN201 | MATERIAL AND ENERGY BALANCES | 3.0 |
| CBEN307 | FLUID MECHANICS | 3.0 |
| CBEN308 | HEAT TRANSFER | 3.0 |
| CBEN357 | CHEMICAL ENGINEERING THERMODYNAMICS | 3.0 |
| CBEN375 | CHEMICAL ENGINEERING SEPARATIONS | 3.0 |
| CBEN418 | KINETICS AND REACTION ENGINEERING | 3.0 |
| Total Semester Hrs | | 18.0 |

## Required Curriculum

## Master of Science Program

## Master of Science (with Thesis)

Students entering the Master of Science (with thesis) program with an acceptable undergraduate degree in chemical engineering are required to take a minimum of 18 semester hours of coursework. All students must complete:

| | | |
|---|---|---|
| **Chemical Engineering core graduate courses** | | |
| CBEN507 | APPLIED MATHEMATICS IN CHEMICAL ENGINEERING | 3.0 |
| CBEN509 | ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS | 3.0 |
| CBEN516 | TRANSPORT PHENOMENA | 3.0 |
| CBEN518 | REACTION KINETICS AND CATALYSIS | 3.0 |
| CBEN568 | INTRODUCTION TO CHEMICAL ENGINEERING RESEARCH AND TEACHING | 3.0 |
| CBEN707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 6.0 |
| ELECT | Approved Coursework Electives | 6.0 |
| RESEARCH | Research Credits or Coursework | 3.0 |
| Total Semester Hrs | | 30.0 |

Students must take a minimum of 6 research credits, complete, and defend an acceptable Masters dissertation. Upon approval of the thesis committee, graduate credit may be earned for 400-level courses. Between coursework and research credits a student must earn a minimum of 30 total semester hours. Full-time Masters students must enroll in graduate colloquium (CBEN605) each semester.

## Master of Science (Non-Thesis)

Students entering the Master of Science (non-thesis) program with an acceptable undergraduate degree in chemical engineering are required to take a minimum of 30 semester hours of coursework. All students must complete:

| | | |
|---|---|---|
| **Chemical Engineering core graduate courses** | | |
| CBEN507 | APPLIED MATHEMATICS IN CHEMICAL ENGINEERING | 3.0 |
| CBEN509 | ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS | 3.0 |
| CBEN516 | TRANSPORT PHENOMENA | 3.0 |
| CBEN518 | REACTION KINETICS AND CATALYSIS | 3.0 |
| ELECT | Approved Electives | 18.0 |
| Total Semester Hrs | | 30.0 |

Students may complete an acceptable engineering report for up to 6 hours of academic credit. Upon approval of the advisor, graduate credit may be earned for selected 400-level courses. Full-time Masters students must enroll in graduate colloquium (CBEN605) each semester.

Mines undergraduates enrolled in the combined BS/MS degree program must meet the requirements described above for the MS portion of their degree (both thesis and non-thesis). Students accepted into the combined program may take graduate coursework and/or research credits as an undergraduate and have them applied to their MS degree.

## Doctor of Philosophy Program

The course of study for the PhD degree consists of a minimum of 30 semester hours of coursework. All PhD students must complete:

| | | |
|---|---|---|
| **Core courses** | | |
| CBEN507 | APPLIED MATHEMATICS IN CHEMICAL ENGINEERING | 3.0 |
| CBEN509 | ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS | 3.0 |
| CBEN516 | TRANSPORT PHENOMENA | 3.0 |
| CBEN518 | REACTION KINETICS AND CATALYSIS | 3.0 |
| CBEN568 | INTRODUCTION TO CHEMICAL ENGINEERING RESEARCH AND TEACHING | 3.0 |
| CBEN630 | PROPOSAL PREPARATION | 1.0 |
| CBEN6XX | 600-Level Coursework Electives | 3.0 |
| ELECT | Approved Coursework Electives | 12.0 |
| CBEN707 | Graduate Research Credit (up to 12 hours per semester) | 42.0 |
| Total Semester Hrs | | 73.0 |

In addition, students must complete and defend an acceptable Doctoral dissertation. Upon approval of the thesis committee, graduate credit may be earned for 400-level courses. Full-time PhD students must enroll in graduate colloquium (CBEN605) each semester.

Students in the PhD program are required to pass both a Qualifying Exam and the PhD Proposal Defense. After successful completion of 30 semester hours of coursework and completion of the PhD proposal defense, PhD candidates will be awarded a non-thesis Master of Science Degree. The additional requirements for the PhD program are described below.

## PhD Qualifying Examination

The PhD qualifying examination will be offered twice each year, at the start and end of the Spring semester. All students who have entered the PhD program must take the qualifying examination at the first possible opportunity. However, a student must be in good academic standing (above 3.0 GPA) to take the qualifying exam. A student may retake the examination once if he/she fails the first time; however, the examination must be retaken at the next regularly scheduled examination time. Failure of the PhD qualifying examination does not disqualify a student for the MS degree, although failure may affect the student's financial aid status.

The qualifying examination will cover the traditional areas of Chemical Engineering, and will consist of two parts: GPA from core graduate classes (CBEN507, CBEN509, CBEN516, and CBEN518) and an oral examination. The oral examination will consist of a presentation by the student on a technical paper from chemical engineering literature. Students will choose a paper from a list determined by the faculty. Papers for the oral examination will be distributed well in advance of the oral portion of the exam so students have sufficient time to prepare their presentations. The student is required to relate the paper to the core chemical engineering classes and present a research plan, followed by questions from the faculty. A 1-2 page paper on the research plan is due the Friday prior to the oral examination.

If a student fails the first attempt at the qualifying exam, his/her grade from a 600 level Chemical Engineering elective can replace the lowest grade from the core graduate classes for, and only for, the GPA calculation defined above.

## PhD Proposal Defense

After passing the Qualifying Exam, all PhD candidates are required to prepare a detailed written proposal on the subject of their PhD research topic. An oral examination consisting of a defense of the thesis proposal must be completed prior to their fifth semester. Written proposals must be submitted to the student's thesis committee no later than one week prior to the scheduled oral examination.

Two negative votes from the doctoral committee members are required for failure of the PhD Proposal Defense. In the case of failure, one re-examination will be allowed upon petition to the Department Head. Failure to complete the PhD Proposal Defense within the allotted time without an approved postponement will result in failure. Under extenuating circumstances a student may postpone the exam with approval of the Graduate Affairs committee, based on the recommendation of the student's thesis committee. In such cases, a student must submit a written request for postponement that describes the circumstances and proposes a new date. Requests for postponement must be presented to the thesis committee no later than 2 weeks before the end of the semester in which the exam would normally have been taken.

## Courses

**CBEN504. ADVANCED PROCESS ENGINEERING ECONOMICS. 3.0 Semester Hrs.**
Advanced engineering economic principles applied to original and alternate investments. Analysis of chemical and petroleum processes relative to marketing and return on investments. Prerequisite: none. 3 hours lecture; 3 semester hours.

**CBEN505. NUMERICAL METHODS IN CHEMICAL ENGINEERING. 3.0 Semester Hrs.**
Engineering applications of numerical methods. Numerical integration, solution of algebraic equations, matrix 54 Colorado School of Mines Graduate Bulletin 2011 2012 algebra, ordinary differential equations, and special emphasis on partial differential equations. Emphasis on application of numerical methods to chemical engineering problems which cannot be solved by analytical methods. Prerequisite: none. 3 hours lecture; 3 semester hours.

**CBEN506. ADVANCED FUNCTIONAL POROUS MATERIALS. 3.0 Semester Hrs.**
Foundation on basic chemical strategies for making nanomaterials. Integration of fundamentals and functional applications of ordered porous materials at different length scales: from micro to macroporous regime. Chemical engineering concepts in nanochemistry. Existing and emerging functional applications of these porous materials in gas separations, heterogeneous catalysis, and adsorption.

**CBEN507. APPLIED MATHEMATICS IN CHEMICAL ENGINEERING. 3.0 Semester Hrs.**
(I, II) This course stresses the application of mathematics to problems drawn from chemical and biological engineering fundamentals such as thermodynamics, transport phenomena, and kinetics. Formulation and solution of ordinary and partial differential equations arising in chemical engineering or related processes or operations are discussed. Prerequisite: Undergraduate differential equations course; undergraduate chemical engineering courses covering reaction kinetics, and heat, mass and momentum transfer. 3 hours lecture; 3 semester hours.

**CBEN509. ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS. 3.0 Semester Hrs.**
Extension and amplification of under graduate chemical engineering thermodynamics. Topics will include the laws of thermodynamics, thermodynamic properties of pure fluids and fluid mixtures, phase equilibria, and chemical reaction equilibria. Prerequisite: CBEN357 or equivalent. 3 hours lecture; 3 semester hours.

**CBEN511. NEUROSCIENCE, MEMORY, AND LEARNING. 3.0 Semester Hrs.**
Equivalent with CBEN411,
(II) This course relates the hard sciences of the brain and neuroscience to memory encoding and current learning theories. Successful students in the course should be able to read, understand, and critique current, scholarly literature on the topic of Neuroscience, Memory, and Learning. When this course is cross-listed and concurrent with CBEN411, students that enroll in CBEN511 will complete additional and/or more complex assignments. Pre-requisites: CBEN110, CBEN120, CHGN221, CHGN222, PHGN100, and PHGN200. 3 hours lecture, 3 semester hours.

**CBEN513. SELECTED TOPICS IN CHEMICAL ENGINEERING. 1-3 Semester Hr.**

Selected topics chosen from special interests of instructor and students. Course may be repeated for credit on different topics. Prerequisite: none. 1 to 3 semester hours lecture/discussion; 1 to 3 semester hours.

**CBEN516. TRANSPORT PHENOMENA. 3.0 Semester Hrs.**

(I) Principles of momentum, heat, and mass transport with applications to chemical and biological processes. Analytical methods for solving ordinary and partial differential equations in chemical engineering with an emphasis on scaling and approximation techniques. Convective transport in the context of boundary layer theory and development of heat and mass transfer coefficients. Introduction to computational methods for solving coupled transport problems in irregular geometries. 3 hours lecture; 3 semester hours.

**CBEN518. REACTION KINETICS AND CATALYSIS. 3.0 Semester Hrs.**

(I) This course applies the fundamentals of kinetics, transport and thermodynamics to the analysis of gas-phase and catalytic reactions. A focus is placed on a molecular description of chemical kinetics with applications to the design and analysis chemical and biological reactors, complex reaction networks, and catalysis. Prerequisite: CBEN418 or equivalent. 3 hours lecture; 3 semester hours.

**CBEN524. COMPUTER-AIDED PROCESS SIMULATION. 3.0 Semester Hrs.**

Advanced concepts in computer-aided process simulation are covered. Topics include optimization, heat exchanger networks, data regression analysis, and separations systems. Use of industry-standard process simulation software (Aspen Plus) is stressed. Prerequisite: none. 3 hours lecture; 3 semester hours.

**CBEN531. IMMUNOLOGY FOR SCIENTISTS AND ENGINEERS. 3.0 Semester Hrs.**

(II) This course introduces the basic concepts of immunology and their applications in engineering and science. We will discuss the molecular, biochemical and cellular aspects of the immune system including structure and function of the innate and acquired immune systems. Building on this, we will discuss the immune response to infectious agents and the material science of introduced implants and materials such as heart valves, artificial joints, organ transplants and lenses. We will also discuss the role of the immune system in cancer, allergies, immune deficiencies, vaccination and other applications such as immunoassay and flow cytometry. Prerequisites: Biology BIOL110 or equivalent or graduate standing.

**CBEN535. INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY. 3.0 Semester Hrs.**

Equivalent with MLGN535,PHGN435,PHGN535,

Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. 1 hour lecture, 4 hours lab; 3 semester hours.

**CBEN550. MEMBRANE SEPARATION TECHNOLOGY. 3.0 Semester Hrs.**

This course is an introduction to the fabrication, characterization, and application of synthetic membranes for gas and liquid separations. Industrial membrane processes such as reverse osmosis, filtration, pervaporation, and gas separations will be covered as well as new applications from the research literature. The course will include lecture, experimental, and computational (molecular simulation) laboratory components. Prerequisites: CBEN375, CBEN430. 3 hours lecture; 3 semester hours.

**CBEN554. APPLIED BIOINFORMATICS. 3.0 Semester Hrs.**

(II) In this course we will discuss the concepts and tools of bioinformatics. The molecular biology of genomics and proteomics will be presented and the techniques for collecting, storing, retrieving and processing such data will be discussed. Topics include analyzing DNA, RNA and protein sequences, gene recognition, gene expression, protein structure prediction, modeling evolution, utilizing BLAST and other online tools for the exploration of genome, proteome and other available databases. In parallel, there will be an introduction to the PERL programming language. Practical applications to biological research and disease will be presented and students given opportunities to use the tools discussed. General Biology BIOL110 or Graduate standing.

**CBEN555. POLYMER AND COMPLEX FLUIDS COLLOQUIUM. 1.0 Semester Hr.**

Equivalent with CHGN555,MLGN555,

The Polymer and Complex Fluids Group at the Colorado School of Mines combines expertise in the areas of flow and field based transport, intelligent design and synthesis as well as nanomaterials and nanotechnology. A wide range of research tools employed by the group includes characterization using rheology, scattering, microscopy, microfluidics and separations, synthesis of novel macromolecules as well as theory and simulation involving molecular dynamics and Monte Carlo approaches. The course will provide a mechanism for collaboration between faculty and students in this research area by providing presentations on topics including the expertise of the group and unpublished, ongoing campus research. Prerequisites: none. 1 hour lecture; 1 semester hour. Repeatable for credit to a maximum of 3 hours.

**CBEN568. INTRODUCTION TO CHEMICAL ENGINEERING RESEARCH AND TEACHING. 3.0 Semester Hrs.**

(I) Students will be expected to apply chemical engineering principles to critically analyze theoretical and experimental research results in the chemical engineering literature, placing it in the context of the related literature, and interact effectively with students in classroom. Skills to be developed and discussed include oral presentations, technical writing, proposal writing, principles of hypothesis driven research, critical review of the literature, research ethics, research documentation (the laboratory notebook), research funding, types of research, pedagogical methods, and assessment tools. Prerequisites: graduate student in Chemical and Biological Engineering in good standing. 3 semester hours.

**CBEN569. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.**

Equivalent with MEGN569,MLGN569,MTGN569,

(I) Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical-thermodynamics and materials- science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. 3 credit hours.

**CBEN570. INTRODUCTION TO MICROFLUIDICS. 3.0 Semester Hrs.**

This course introduces the basic principles and applications of microfluidics systems. Concepts related to microscale fluid mechanics, transport, physics, and biology are presented. To gain familiarity with small-scale systems, students are provided with the opportunity to design, fabricate, and test a simple microfluidic device. Students will critically analyze the literature in this emerging field. Prerequisites: CBEN307 or equivalent. 3 hours lecture, 3 semester hours.

**CBEN580. NATURAL GAS HYDRATES. 3.0 Semester Hrs.**
The purpose of this class is to learn about clathrate hydrates, using two of the instructor's books, (1) Clathrate Hydrates of Natural Gases, Third Edition (2008) co authored by C.A.Koh, and (2) Hydrate Engineering, (2000). Using a basis of these books, and accompanying programs, we have abundant resources to act as professionals who are always learning. 3 hours lecture; 3 semester hours.

**CBEN584. FUNDAMENTALS OF CATALYSIS. 3.0 Semester Hrs.**
The basic principles involved in the preparation, charac terization, testing and theory of heterogeneous and homo geneous catalysts are discussed. Topics include chemisorption, adsorption isotherms, diffusion, surface kinetics, promoters, poisons, catalyst theory and design, acid base catalysis and soluble transition metal complexes. Examples of important industrial applications are given. Prerequisite: none. 3 hours lecture; 3 semester hours.

**CBEN598. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**CBEN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**CBEN604. TOPICAL RESEARCH SEMINARS. 1.0 Semester Hr.**
Lectures, reports, and discussions on current research in chemical engineering, usually related to the student?s thesis topic. Sections are operated independently and are directed toward different research topics. Course may be repeated for credit. Prerequisite: none. 1 hour lecture-discussion; 1 semester hour. Repeatable for credit to a maximum of 3 hours.

**CBEN605. COLLOQUIUM. 1.0 Semester Hr.**
Students will attend a series of lectures by speakers from industry, academia, and government. Primary emphasis will be on current research in chemical engineering and related disciplines, with secondary emphasis on ethical, philosophical, and career-related issues of importance to the chemical engineering profession. Prerequisite: Graduate status.

**CBEN608. ADVANCED TOPICS IN FLUID MECHANICS. 1-3 Semester Hr.**
Indepth analysis of selected topics in fluid mechanics with special emphasis on chemical engineering applications. Prerequisite: CBEN508. 1 to 3 hours lecture discussion; 1 to 3 semester hours.

**CBEN609. ADVANCED TOPICS IN THERMODYNAMICS. 1-3 Semester Hr.**
Advanced study of thermodynamic theory and application of thermodynamic principles. Possible topics include stability, critical phenomena, chemical thermodynamics, thermodynamics of polymer solutions and thermodynamics of aqueous and ionic solutions. Prerequisite: none. 1 to 3 semester hours.

**CBEN610. APPLIED STATISTICAL THERMODYNAMICS. 3.0 Semester Hrs.**
Principles of relating behavior to microscopic properties. Topics include element of probability, ensemble theory, application to gases and solids, distribution theories of fluids, and transport properties. Prerequisite: none. 3 hours lecture; 3 semester hours.

**CBEN617. GRADUATE TRANSPORT PHENOMENA II. 3.0 Semester Hrs.**
(II) Analysis of momentum, heat, and mass transfer problems using advanced analytical and numerical methods with an emphasis on coupled transport problems and irregular geometries. Advanced analytical techniques may include regular and singular perturbation analysis, eigenvalue problems, finite Fourier transforms, and Laplace transforms. Numerical methods for solving differential equations include finite differences, finite elements, Monte Carlo methods, and computational fluid dynamics. Prerequisite: CBEN516. 3 hours lecture; 3 semester hours.

**CBEN620. ENGINEERING OF SOFT MATTER. 3.0 Semester Hrs.**
(II) Soft matter is a field of inquiry involving physical systems having low moduli and which are structured on length scales ranging from about 10 nanometers up to 100 microns. This graduate level class provides a survey of relevant material systems including polymers, colloids, surfactants, liquid crystals, and biological materials. The course emphasis is on the chemical physics of soft materials and therefore requires a high level of mathematical sophistication; students should have the equivalent of one semester of graduate level applied mathematics as a prerequisite. A term paper in the form of a short publishable review of a relevant topic is a major component of the class. Prerequisites: the equivalent of one semester of graduate level applied mathematics. 3 hours lecture; 3 semester hours.

**CBEN624. APPLIED STATISTICAL MECHANICS. 3.0 Semester Hrs.**
This course will introduce the both rigorous and approximate theories to estimate the macroscopic thermodynamic properties of systems based on laws that control the behavior of molecules. Course contents include classical dynamics and phase space, different types of ensembles, ideal and interacting gases, modern theory of liquids, ideal solids, as well as molecular simulation techniques. Prerequisite: Undergraduate-level classical thermodynamics.

**CBEN625. MOLECULAR SIMULATION. 3.0 Semester Hrs.**
Principles and practice of modern computer simulation techniques used to understand solids, liquids, and gases. Review of the statistical foundation of thermodynamics followed by in-depth discussion of Monte Carlo and Molecular Dynamics techniques. Discussion of intermolecular potentials, extended ensembles, and mathematical algorithms used in molecular simulations. Prerequisites: CBEN509 or equivalent, CBEN610 or equivalent recommended. 3 hours lecture; 3 semester hours.

**CBEN630. PROPOSAL PREPARATION. 1.0 Semester Hr.**
(I) This course is designed to guide students through the steps in writing a proposal. The Proposal writing process is divided into logical steps each of which when completed will lead to the graduate student having a draft proposal that could be successfully defended. Topics include: how to conduct a literature search and maintain an up to date database of relevant sources; Writing of a literature review in the context of a proposal; how to write a testable scientific hypothesis; the format and writing of a scientific paper; how best to present data and errors; an understanding of ethics and plagiarism issues; writing of a work plan with tasks related to objectives and time budget, Gantt charts; creation of a project budget; presentation techniques and oral defense of the proposal. 1 hour lecture; 1 semester. hour. Repeatable.

**CBEN690. SUPERVISED TEACHING OF CHEMICAL ENGINEERING. 3.0 Semester Hrs.**
(I) Individual participation in teaching, outreach, and/or pedagogical research activities. Discussion, problem review and development, guidance of laboratory experiments, course development, supervised practice teaching. 6 to 10 hours supervised teaching; 3 semester hours. Prerequisite: Good academic standing, CBEN 507, CBEN 509, CBEN 516, CBEN 518.

**CBEN698. SPECIAL TOPICS IN CHEMICAL ENGINEERING. 3.0 Semester Hrs.**
Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles. Prerequisite: none.

**CBEN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**CBEN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

## Professors

Sumit Agarwal

Anuj Chauhan, Department Head

Andrew M. Herring

Carolyn A. Koh, William K. Coors Distinguished Chair of Chemical and Biological Engineering

David W.M. Marr

Amadeu Sum

Colin A. Wolden

David T.W. Wu

## Associate Professors

Moises A. Carreon

Ning Wu

## Assistant Professors

Nanette Boyle

Kevin J. Cash

Nikki Farnsworth

Diego A. Gómez-Gualdrón

Melissa D. Krebs

Stephanie Kwon

Joseph R. Samaniuk

## Teaching Associate Professors

Jason C. Ganley, Assistant Department Head

Tracy Q. Gardner

Rachel M. Morrish

Cynthia L. Norrgran

C. Joshua Ramey

Justin Shaffer

## Teaching Assistant Professor

Michael D.M. Barankin

## Professor of Practice

John L. Jechura

## Professors Emeriti

Robert M. Baldwin

Annette L. Bunge

Anthony M. Dean

James F. Ely, University Professor Emeritus

John O. Golden

J. Thomas McKinnon

Ronald L. Miller

E. Dendy Sloan, Jr. , University Professor Emeritus

Charles Vestal

J. Douglas Way

Victor F. Yesavage

# Civil and Environmental Engineering

## Degrees Offered

- Master of Science in Civil and Environmental Engineering
- Doctor of Philosophy in Civil and Environmental Engineering
- Master of Science in Environmental Engineering Science
- Doctor of Philosophy in Environmental Engineering Science
- Graduate Certificate in Environmental Modeling

## Program Description

The Civil and Environmental Engineering Department offers two MS and PhD graduate degrees - Civil & Environmental Engineering (CEE) and Environmental Engineering Science (EES).

The Civil and Environmental Engineering (CEE) degree is designed for students who wish to earn a degree to continue the path towards a professional engineering registration. Students entering this degree program should have a BS degree in engineering or will generally need to take engineering prerequisite courses. Within the CEE degree, students complete specified requirements in one of three different emphasis areas: Environmental and Water Engineering (EWE), Geotechnical Engineering (GT), and Structural Engineering (SE).

The Environmental Engineering Science (EES) degree does not require engineering credentials and has a flexible curriculum that enables students with a baccalaureate degree in biology, chemistry, math, physics, geology, engineering, and other technical fields, to tailor a course-work program that best fits their career goals. The MS and PhD degrees in Environmental Engineering Science (EES) has been admitted to the Western Regional Graduate Program (WRGP/WICHE), a recognition that designates this curriculum as unique within the Western United States. An important benefit of this designation is that students who are residents from Alaska, Arizona, California, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming are given the tuition status of Colorado residents.

The specific requirements for the EES & CEE degrees, as well as for the four emphasis areas within the CEE degree, are described in detail under the Major tab.

To achieve the Master of Science (MS) degree, students may elect the Non-Thesis option, based exclusively upon coursework and project activities, or the Thesis option, which requires coursework and rigorous research conducted under the guidance of a faculty advisor and MS thesis committee, that is described in a final written thesis that is defended in an oral presentation.

The Doctor of Philosophy (PhD) degree requires students to complete a combination of coursework and original research, under the guidance of a faculty advisor and doctoral committee, that culminates in a significant scholarly contribution (e.g., in the form of published journal articles) to a specialized field in Civil and Environmental Engineering or Environmental Engineering Science. The written thesis must be defended in a public oral presentation before the advisor and thesis committee. The PhD program may build upon one of the CEE or EES MS programs or a comparable MS program at another university. Full-time PhD enrollment is expected and leads to the greatest success, although part-time enrollment may be allowed under special circumstances.

**Faculty Expertise and General Emphasis Areas:**

Civil and Environmental Engineering faculty have expertise in environmental science and engineering, geotechnical engineering, hydrology, water-resources engineering, structural engineering, and underground construction and tunneling. These areas also serve as topic areas for coursework and for MS thesis or PhD thesis research, and are the basis for degree requirements.

## Civil and Environmental Engineering

**Geotechnical Engineering**: Geotechnical Engineering is concerned with the engineering properties and behavior of natural and engineered geomaterials (soils and rocks), as well as the design and construction of foundations, earth dams and levees, retaining walls, embankments, underground structures and tunnels. Almost all constructed projects require input from geotechnical engineers as most structures are built on, in or of geomaterials. Additionally, mitigation of the impact of natural hazards such as earthquakes and landslides, sustainable use of energy and resources, and reduction of the environmental impacts of human activities require geotechnical engineers who have in-depth understanding of how geomaterials respond to loads, and environmental changes. Students who pursue this discipline complete the requirements of the Geotechnical Engineering emphasis area within the Civil & Environmental Engineering degree program.

**Structural Engineering**: Is a multidisciplinary subject spanning the disciplines of civil engineering, aerospace engineering, mechanical engineering, and marine engineering. In all these disciplines, structural engineers use engineered materials and conduct analyses using general principles of structural mechanics, to design structures for civil systems. Designed systems may include bridges, dams, buildings, tunnels, sustainable infrastructure, highways, biomechanical apparatus, sustainable civil engineering materials and numerous other structures and devices. Students who pursue this discipline complete the requirements of the Structural Engineering (SE) emphasis area within the Civil & Environmental Engineering Degree program.

**Environmental and Water Engineering**: Is the application of environmental processes in natural and engineered systems. CEE faculty have expertise in water resource engineering, biosystems engineering, environmental chemistry, environmental microbiology, microbial genomics, wastewater treatment, water treatment, bioremediation, mining treatment processes and systems, remediation processes, biogeochemical reactions in soils, geobiology, membrane processes, humanitarian engineering, social aspects of engineering, and energy recovery from fluids.

## Environmental Engineering Science

**Environmental Engineering and Science**: Is the application of environmental processes in natural and engineered systems. CEE faculty have expertise in water resource engineering, biosystems engineering, environmental chemistry, environmental microbiology, microbial genomics, wastewater treatment, water treatment, bioremediation, mining treatment processes and systems, remediation processes, biogeochemical reactions in soils, geobiology, membrane processes, humanitarian engineering, social aspects of engineering, and energy recovery from fluids.

## Affiliated Interdisciplinary Degrees

**Hydrologic Science and Engineering (HSE)** offers interdisciplinary programs of study in fundamental hydrologic science and applied hydrology with engineering applications. Our program encompasses groundwater hydrology, surface-water hydrology, vadose-zone hydrology, watershed hydrology, contaminant transport and fate, contaminant remediation, hydrogeophysics, and water policy/law. HSE is part of the Western Regional Graduate Program (WICHE), a recognition that designates the program as unique within the Western United States. An important benefit of this designation is that students from several western states are given the tuition status of Colorado residents. These states include Alaska, Arizona, California, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming.

The graduate degree program in HSE is offered jointly the Departments of Chemistry and Geochemistry, Civil & Environmental Engineering (CEE), Geology and Geological Engineering (GE), Geophysical Engineering, Humanities, Arts, and Social Sciences (HASS), Mechanical Engineering (ME), Mining Engineering (MN), and Petroleum Engineering (PE). Participating students reside in one of these departments, typically the home department of their advisor.

For more information, see the HSE section of this graduate catalog, listed under Interdisciplinary Programs..

**Underground Construction and Tunnel Engineering** (UCTE) is an interdisciplinary field involving civil engineering, geological engineering and mining engineering, as well as involving mechanical engineering, electrical engineering, geophysics, geology and others. UCTE deals with the design, construction, rehabilitation and management of underground space including caverns, shafts and tunnels for commercial, transportation, water and wastewater use. UCTE is a challenging field involving complex soil and rock behavior, groundwater conditions, excavation methods, construction materials, structural design flow, heterogeneity, and very low tolerance for deformation due to existing infrastructure in urban environments. Students pursuing a graduate degree in UCTE will gain a strong and interdisciplinary foundation in these topics.

The graduate degree program in UCTE is offered jointly by the Departments of Civil & Environmental Engineering (CEE), Geology & Geological Engineering (GEGN), and Mining Engineering (MN). UCTE faculty from each department are collectively responsible for the operations of the program. Participating students reside in one of these departments, typically the home department of their advisor.

For more information, see the UCTE section of this graduate catalog, listed under Interdisciplinary Programs.

## Program Requirements

## General Degree Requirements for CEE and EES degrees:

MS Non-Thesis Option: 30 total credit hours, consisting of coursework (27 hrs.) and either a three credit hour research based Independent Study (CEEN599 (https://catalog.mines.edu/search/?P=CEEN599A/)) or a designated design course (3 hrs.) and seminar.

MS Thesis Option: 30 total credit hours, consisting of coursework (24 hrs.), seminar, and research (6 hrs.). Students must also write and orally defend a research thesis.

PhD: 72 total credit hours, consisting coursework (at least 24 hrs.), seminar, and research (at least 24 hrs.). Students must also successfully complete qualifying examinations, prepare and present a thesis proposal, and write and defend a doctoral thesis. PhD students are also expected to submit the thesis work for publication in scholarly journals.

## PhD Qualifying Exam in the Department of Civil and Environmental Engineering

The student's Graduate Faculty Advisor in conjunction with the Graduate Thesis Committee administers the PhD Qualifying Exam in CEE. It is designed to test some of the attributes considered essential to successful doctoral level scholarship, including critical thinking, creativity, the potential to conduct successful research, and written and oral communication skills. The student should take the exam within four semesters of enrollment in the doctoral program unless the Committee grants an extension.

The conduct of the Qualifying Exam is flexible, but typically involves both written and oral components. The written assignments might include several take-home questions set by members of the Committee, and a review or research paper on a topic related to the student's intended research area. As soon as practicable following return of the completed exam materials to the Advisor, a 1-2 hour meeting of the Committee is scheduled for the oral component of the Qualifying Exam, during which the student may make an oral presentation of the paper, followed by further oral exam of the other written materials and any other topics deemed appropriate by the Committee. Following the meeting, the student is informed of the result of the examination (pass/fail), and the Advisor informs the Department Head and Graduate Program Manager of the outcome. The duration of the written exam is set by the Committee, but is expected to be quite short (e.g. 1 week).

In the event the student does not pass the Qualifying Exam, he/she may petition the Department Head for a re-examination within six months. If permission is granted, the dates of the re-examination are arranged in conjunction with the Advisor and Committee, and follows exactly the same guidelines as before.

A second failure of the Qualifying Exam does not disqualify a student for the MS degree but may affect the student's financial support status, and will result in a recommendation from the CEE Department Head to the Graduate School that the student be dismissed from the CEE or EES PhD program.

## PhD Proposal Defense in the Department of Civil and Environmental Engineering

The student's Graduate Faculty Advisor in conjunction with the Graduate Thesis Committee administers the PhD Proposal Defense in CEE. The purpose of the thesis proposal is to describe the student's research and enable evaluation of its viability to ensure timely progress toward attainment of the PhD degree. In general, the written proposal will describe the purpose and scope of work, anticipated results, literature review, preliminary findings, proposed research approach and methodologies, along with a schedule. No later than two weeks following submission of the thesis proposal to the Committee, the student and Committee will meet for an oral presentation of 1-2 hours, during which the student will be questioned about matters immediately relevant to the thesis proposal. The Committee will reach a decision as to whether the proposed research is appropriate and achievable for a CEE or ESE PhD degree. Following the meeting, the student is informed of whether the proposal has been approved, and the Advisor informs the Department Head and Graduate Program Manager of the outcome.

In the event the student does not pass the Proposal Defense, he/she may petition the Department Head for a re-examination within six months. If permission is granted, the proposal can be revised for reconsideration by the Committee, following exactly the same guidelines as before.

A second Proposal Defense failure will result in a recommendation from the CEE Department Head to the Graduate School that the student be dismissed from the CEE or ESE PhD program.

A PhD student must obtain approval of his/her thesis proposal by the Committee at least one year before the final thesis defense.

## Mines' Combined Undergraduate / Graduate Degree Program

The Civil & Environmental Engineering Combined undergraduate/graduate program allows courses at the 400 level and above, for the Mines degree programs listed below, to be used for double counting. Students with uninterrupted registration from the time a Mines undergraduate degree is earned to the time a Mines graduate degree begins are eligible. For eligible students whose courses meet these criteria, have been passed with a "B-" or better, and meet all other University, Department, Division, and Program requirements for graduate credit, up to 6 credit hours can be double counted, per the Mines Graduate Catalog. Undergraduate Degree programs:

Civil Engineering

Environmental Engineering

Chemical & Biological Engineering

Chemistry

Geological Engineering

Geophysics

Mechanical Engineering

Petroleum Engineering

Mining Engineering

Students from other Mines undergraduate degree programs should contact the CEE department to discuss course options for double counting.

## Civil and Environmental Engineering

## Prerequisites for CEE Degree:

- Baccalaureate degree: required, preferably in a science or engineering discipline
- College calculus I & II: two semesters required
- College physics: one semester required, two semesters highly recommended
- College chemistry I & II: two semesters required
- College probability & statistics: one semester required
- Statics
- Dynamics or Mechanics of Materials
- Differential Equations
- **Emphasis Area Additional Requirements:**
  - **Geotechnical and Structural -** soil mechanics, structural theory/structural analysis
  - **Environmental and Water -** fluid mechanics

### Required Curriculum for Civil and Environmental Engineering (CEE) Degree:

The CEE curriculum contains 3 emphasis areas: Environmental and Water Engineering, Geotechnical Engineering, and Structural Engineering. CEE students must complete the requirements for at least one emphasis area.

Core Courses: Each emphasis area has required core courses that apply to MS and PhD degrees. These core courses are listed below.

**Electives**: A variety of engineering courses may be taken for electives in the CEE emphasis areas, including additional CEEN courses, as well as courses from other departments on campus. The student's advisor and committee must approve elective courses. Students must take at least 21 elective credits within the CEEN prefix.

## CEE Degree Emphasis Areas

## Geotechnical Engineering

***Additional Prerequisites Courses:*** soil mechanics, structural theory/structural analysis

**Geotechnical Core Courses:** Students are required to successfully complete three courses (9 credit hours) from the following core course list plus CEEN590 (https://catalog.mines.edu/search/?P=CEEN590/) Civil Engineering seminar.

| | | |
|---|---|---|
| CEEN510 | ADVANCED SOIL MECHANICS | 3.0 |
| CEEN511 | UNSATURATED SOIL MECHANICS | 3.0 |
| CEEN512 | SOIL BEHAVIOR | 3.0 |
| CEEN515 | HILLSLOPE HYDROLOGY AND STABILITY | 3.0 |
| CEEN523 | UNDERGROUND CONSTRUCTION ENGINEERING IN SOFT GROUND * | 4.0 |
| CEEN519 | RISK ASSESSMENT IN GEOTECHNICAL ENGINEERING | 3.0 |
| CEEN506 | FINITE ELEMENT METHODS FOR ENGINEERS | 3.0 |

* Design Course

## Structural Engineering

***Additional Prerequisites Courses***: soil mechanics, structural theory / structural analysis.

**Structural Engineering Core Courses:** Students are required to successfully complete three courses (9 credit hours) from the following core course list plus CEEN590 (https://catalog.mines.edu/search/?P=CEEN590/) Civil Engineering seminar.

| | | |
|---|---|---|
| CEEN506 | FINITE ELEMENT METHODS FOR ENGINEERS | 3.0 |
| CEEN530 | ADVANCED STRUCTURAL ANALYSIS | 3.0 |
| CEEN531 | STRUCTURAL DYNAMICS | 3.0 |
| CEEN540 | ADVANCED DESIGN OF STEEL STRUCTURES * | 3.0 |
| CEEN541 | DESIGN OF REINFORCED CONCRETE STRUCTURES II * | 3.0 |
| CEEN542 | TIMBER AND MASONRY DESIGN * | 3.0 |

| | | |
|---|---|---|
| CEEN543 | CONCRETE BRIDGE DESIGN BASED ON THE AASHTO LRFD SPECIFICATIONS * | 3.0 |

* Design Course

## Environmental and Water Engineering

***Additional Prerequisites Courses:*** fluid mechanics.

**Environmental & Water Engineering Core Courses:** Students are required to successfully complete one course as specified in each of the following areas plus CEEN596 Environmental Seminar:

| | | |
|---|---|---|
| **Chemistry** | | |
| CEEN550 | PRINCIPLES OF ENVIRONMENTAL CHEMISTRY | 3.0 |
| **Physical Transport** | | |
| CEEN580 | CHEMICAL FATE AND TRANSPORT IN THE ENVIRONMENT | 3.0 |
| **Bio Processes** | | |
| CEEN566 | MICROBIAL PROCESSES, ANALYSIS AND MODELING * | 3.0 |
| or CEEN560 | MOLECULAR MICROBIAL ECOLOGY AND THE ENVIRONMENT | |
| or CEEN562 | ENVIRONMENTAL GEOMICROBIOLOGY | |
| **Systems Design** | | |
| CEEN570 | WATER AND WASTEWATER TREATMENT * (Both are Design Courses) | 3.0 |
| or CEEN471 | WATER AND WASTEWATER TREATMENT SYSTEMS ANALYSIS AND DESIGN | |
| **Seminar** | | |
| CEEN596 | ENVIRONMENTAL SCIENCE AND ENGINEERING SEMINAR | 0.0 |

*Design Course

## Environmental Engineering Science

## Prerequisites for EES degree:

- Baccalaureate degree: required, preferably in a science or engineering discipline
- College calculus I & II: two semesters required
- College physics: one semester required, two semesters highly recommended
- College chemistry I & II: two semesters required
- College probability & statistics: one semester required

### Required Curriculum for Environmental Engineering Science (EES) Degree:

The EES curriculum consists of common core and elective courses that may be focused toward specialized areas of emphasis. The common core includes:

| | | |
|---|---|---|
| CEEN550 | PRINCIPLES OF ENVIRONMENTAL CHEMISTRY | 3.0 |
| CEEN580 | CHEMICAL FATE AND TRANSPORT IN THE ENVIRONMENT | 3.0 |
| CEEN566 | MICROBIAL PROCESSES, ANALYSIS AND MODELING * | 3.0 |
| or CEEN560 | MOLECULAR MICROBIAL ECOLOGY AND THE ENVIRONMENT | |
| or CEEN562 | ENVIRONMENTAL GEOMICROBIOLOGY | |
| ENVIRONMENTAL BASED LAW OR POLICY COURSE Commonly HASS Courses | | 3.0 |
| CEEN596 | ENVIRONMENTAL SCIENCE AND ENGINEERING SEMINAR | 0.0 |
| CEEN ELECT | 3.0 CR INDEPENDENT STUDY OR 3.0 cr DESIGN COURSE | 3.0 |

*Design Course

**Electives**: A variety of engineering courses may be taken for electives in the CEE emphasis areas, including additional CEEN courses, as well as courses from other departments on campus. The student's advisor and committee must approve elective courses. Students must take at least 21 elective credits within the CEEN prefix.

## Program Requirements

## Graduate Certificate in Environmental Modeling (12 credit hours)

The Environmental modeling graduate Certificate is an online or residential program focusing on the tools and methods for modeling environmental impacts of systems. Students will learn basic environmental modeling methods such as chemical fate and transport, risk assessment, microbial processes, and systems analysis. Students will also have 3 credits worth of flexibility to customize their certificate as they may select from environmental modeling courses to complete their certificate. The Certificate balances an introduction to environmental issues with a deep dive into environmental modeling. Students will gain perspective on the kinds of problems that can be solved with environmental modeling and will also acquire valuable modeling skills. Moreover, the coursework will cover a broad range of applications, making it relevant for varied scientific and engineering domains.

The 3 core courses in the certificate include:

| | | |
|---|---|---|
| CEEN580 | CHEMICAL FATE AND TRANSPORT IN THE ENVIRONMENT | 3.0 |
| CEEN566 | MICROBIAL PROCESSES, ANALYSIS AND MODELING | 3.0 |
| CEEN501 | LIFE CYCLE ASSESSMENT | 3.0 |
| ELECTIVE | Select 1 course from Electives | 3.0 |

Students will select one elective to complete their certificate from the following (this list will be expanded as more courses come online):

| | | |
|---|---|---|
| DSCI403/ CSCI303 | INTRODUCTION TO DATA SCIENCE | 3.0 |
| DSCI/CSCI470 | INTRODUCTION TO MACHINE LEARNING | 3.0 |
| DSCI/MATH530 | STATISTICAL METHODS I | 3.0 |
| DSCI/MATH560 | INTRODUCTION TO KEY STATISTICAL LEARNING METHODS I | 3.0 |
| GEOL557 | EARTH RESOURCE DATA SCIENCE 1: FUNDAMENTALS | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |

| | | |
|---|---|---|
| EBGN525 | BUSINESS ANALYTICS | 3.0 |
| MEGN586 | LINEAR OPTIMIZATION | 3.0 |

## Courses

**CEEN501. LIFE CYCLE ASSESSMENT. 3.0 Semester Hrs.**

(II) Which is more sustainable: paper vs plastic, hybrid vs electric vehicles? LCA is a powerful tool used to answer these questions; LCA quantifies the environmental sustainability of a product or process. Students will learn to conduct an LCA during a semester-long project of their choosing. At the end of the course students should be able to sit for the ACLCA professional LCACP certification exam. 3 hours lecture; 3 semester hours.

**CEEN505. NUMERICAL METHODS FOR ENGINEERS. 3.0 Semester Hrs.**

(S) Introduction to the use of numerical methods in the solution of commonly encountered problems of engineering analysis. Structural/solid analysis of elastic materials (linear simultaneous equations); vibrations (roots of nonlinear equations, initial value problems); natural frequency and beam buckling (eigenvalue problems); interpretation of experimental data (curve fitting and differentiation); summation of pressure distributions (integration); beam deflections (boundary value problems). All course participants will receive source code of all the numerical methods programs published in the course textbook which is coauthored by the instructor. Prerequisite: MATH225. 3 hours lecture; 3 semester hours.

**CEEN506. FINITE ELEMENT METHODS FOR ENGINEERS. 3.0 Semester Hrs.**

(II) A course combining finite element theory with practical programming experience in which the multidisciplinary nature of the finite element method as a numerical technique for solving differential equations is emphasized. Topics covered include simple structural elements, beams on elastic foundations, solid elasticity, steady state analysis and transient analysis. Some of the applications will lie in the general area of geomechanics, reflecting the research interests of the instructor. Students get a copy of all the source code published in the course textbook. 3 hours lecture; 3 semester hours. Prerequisite: Consent of the instructor.

**CEEN510. ADVANCED SOIL MECHANICS. 3.0 Semester Hrs.**

Advanced soil mechanics theories and concepts as applied to analysis and design in geotechnical engineering. Topics covered will include seepage, consolidation, shear strength, failure criteria and constitutive models for soil. The course will have an emphasis on numerical solution techniques to geotechnical problems by finite elements and finite differences. Prerequisites: A first course in soil mechanics. 3 Lecture Hours, 3 semester hours. Fall even years.

**CEEN511. UNSATURATED SOIL MECHANICS. 3.0 Semester Hrs.**

The focus of this course is on soil mechanics for unsaturated soils. It provides an introduction to thermodynamic potentials in partially saturated soils, chemical potentials of adsorbed water in partially saturated soils, phase properties and relations, stress state variables, measurements of soil water suction, unsaturated flow laws, measurement of unsaturated permeability, volume change theory, effective stress principle, and measurement of volume changes in partially saturated soils. The course is designed for seniors and graduate students in various branches of engineering and geology that are concerned with unsaturated soil?s hydrologic and mechanics behavior. When this course is cross-listed and concurrent with CEEN412, students that enroll in CEEN511 will complete additional and/or more complex assignments. Prerequisites: CEEN312. 3 hours lecture; 3 semester hours. Spring even years.

**CEEN512. SOIL BEHAVIOR. 3.0 Semester Hrs.**

(I) The focus of this course is on interrelationships among the composition, fabric, and geotechnical and hydrologic properties of soils that consist partly or wholly of clay. The course will be divided into two parts. The first part provides an introduction to the composition and fabric of natural soils, their surface and pore-fluid chemistry, and the physico-chemical factors that govern soil behavior. The second part examines what is known about how these fundamental characteristics and factors affect geotechnical properties, including the hydrologic properties that govern the conduction of pore fluid and pore fluid constituents, and the geomechanical properties that govern volume change, shear deformation, and shear strength. The course is designed for graduate students in various branches of engineering and geology that are concerned with the engineering and hydrologic behavior of earth systems, including geotechnical engineering, geological engineering, environmental engineering, mining engineering, and petroleum engineering. When this course is cross-listed and concurrent with CEEN411, students that enroll in CEEN512 will complete additional and/ or more complex assignments. Prerequisites: CEEN361 Soil Mechanics. 3 hours lecture; 3 semester hours.

**CEEN513. ADVANCED GEOMATERIAL MECHANICS. 4.0 Semester Hrs.**

(I) This course deals with the classification and engineering behavior of soil and rock materials as well as materials used in underground construction such as structural steel, aggregates, cement, timber, concrete, shotcrete, accelerators and ground conditioning agents. This course presents an advanced treatment of soil and rock mechanics with focus on the following topics: Index and classification properties of soils, Physical properties and classification of intact rock and rock masses, Fluid flow in soils and rocks, Compressibility of soils and rocks, Failure theories and strength testing of soils and rocks, Shear strength of soils and rocks, Stresses and deformations around underground openings, Laboratory and field methods for evaluation of soil and rock properties, and Analytical and empirical approaches for the design and construction of structures in soil and rock materials. Prerequisites: Undergraduate degree in a pertinent discipline of engineering or equivalent and undergraduate level knowledge of material behavior. Co-requisites: GEGN561. 4 hours lecture; 4 semester hours.

**CEEN515. HILLSLOPE HYDROLOGY AND STABILITY. 3.0 Semester Hrs.**

(I) Introduction of shallow landslide occurrence and socio-economic dynamics. Roles of unsaturated flow and stress in shallow landslides. Slope stability analysis based on unsaturated effective stress conceptualization. Computer modeling of unsaturated flow and stress distributions in hillslope. Prediction of precipitation induced shallow landslides. Prerequisite: CEEN312. 3 hours lecture; 3 semester hours.

**CEEN519. RISK ASSESSMENT IN GEOTECHNICAL ENGINEERING. 3.0 Semester Hrs.**

Soil and rock are among the most variable of all engineering materials, and as such are highly amenable to a probabilistic treatment. Assessment of the probability of failure or inadequate performance is rapidly gaining ground on the traditional factor of safety approach as a more rational approach to design decision making and risk management. Probabilistic concepts are also closely related to system reliability and Load and Resistance Factor Design (LRFD). When probability is combined with consequences of failure, this leads to the concept of risk. This course is about the theory and application of various tools enabling risk assessment in engineering with an emphasis on geotechnical applications.

**CEEN523. UNDERGROUND CONSTRUCTION ENGINEERING IN SOFT GROUND. 4.0 Semester Hrs.**

(II) Design and construction of water, wastewater, transportation and utility tunnels, underground space and shafts/excavations in soft ground conditions (soil and weak rock). Addresses geotechnical site characterization, selection of design parameters, stability and deformation analysis of the ground and overlying structures, and construction methods. Includes design of temporary and permanent structural ground support according to ASD (allowable stress design) and LRFD (load resistance factor design) approaches, and design of ground improvement schemes and instrumentation/monitoring approaches to mitigate risk. This course requires post-graduate level knowledge of soil mechanics, fundamental understanding of engineering geology, and an undergraduate level knowledge of structural analysis and design. Prerequisites: CEEN513 and GEGN468. Co-requisites: GEGN562. 4 hours lecture; 4 semester hours.

**CEEN525. CEMENTITIOUS MATERIALS FOR CONSTRUCTION. 3.0 Semester Hrs.**

Cementitious materials, as the most commonly used construction materials, are the main focus of this course and variety of cementitious materials including Portland and non-Portland cements, supplementary cementitious materials, concrete and sprayed concrete (shotcrete), and grouts with their needed additional constituents are covered in this course. This course provides a comprehensive treatment of engineering principles and considerations for proper design, production, placement and maintenance of high quality cementitious materials for infrastructure. In addition, cementitious materials and techniques used for ground improvement purposes are covered in this course. Prerequisite: CEEN311.

**CEEN530. ADVANCED STRUCTURAL ANALYSIS. 3.0 Semester Hrs.**

(I) Introduction to advanced structural analysis concepts. Nonprismatic structures. Arches, Suspension and cable-stayed bridges. Structural optimization. Computer Methods. Structures with nonlinear materials. Internal force redistribution for statically indeterminate structures. Graduate credit requires additional homework and projects. Prerequisite: CEEN314. 3 hour lectures, 3 semester hours.

**CEEN531. STRUCTURAL DYNAMICS. 3.0 Semester Hrs.**

An introduction to the dynamics and earthquake engineering of structures is provided. Subjects include the analysis of linear and nonlinear single-degree and multi-degree of freedom structural dynamics. The link between structural dynamics and code-based analysis and designs of structures under earthquake loads is presented. he focus applicaitons of the course include single story and multi-story buildings, and other types of sructures that under major earthquake may respond in the inelastic range. Prerequisites: CEEN314 Structural Theory. 3 semester hours.

**CEEN533. MATRIX STRUCTURAL ANALYSIS. 3.0 Semester Hrs.**

Equivalent with CEEN433,

(II) Focused study on computer oriented methods for solving determinate and indeterminate structures such as trusses and frames. Classical stiffness based analysis method will be introduced with hands-on practice to develop customized matrix analysis program using Matlab. Commercial structural analysis programs will also be introduced during the class and practiced through class projects. When this course is cross-listed and concurrent with CEEN433, students that enroll in CEEN533 will complete additional and/or more complex assignments. Prerequisites: CEEN314 Elementary Structural Theory. 3 lecture hours, 3 semester hours.

**CEEN540. ADVANCED DESIGN OF STEEL STRUCTURES. 3.0 Semester Hrs.**

The course extends the coverage of steel design to include the topics: slender columns, beam-columns, frame behavior, bracing systems and connections, stability, moment resisting connections, composite design, bolted and welded connections under eccentric loads and tension, and semi-rigid connections. Prerequisite: CEEN443 or equivalent. 3 hours lecture; 3 semester hours. Spring even years.

**CEEN541. DESIGN OF REINFORCED CONCRETE STRUCTURES II. 3.0 Semester Hrs.**

Advanced problems in the analysis and design of concrete structures, design of slender columns; biaxial bending; two-way slabs; strut and tie models; lateral and vertical load analysis of multistory buildings; introduction to design for seismic forces; use of structural computer programs. Prerequisite: CEEN445. 3 hour lectures, 3 semester hours. Delivered in the spring of even numbered years.

**CEEN542. TIMBER AND MASONRY DESIGN. 3.0 Semester Hrs.**

The course develops the theory and design methods required for the use of timber and masonry as structural materials. The design of walls, beams, columns, beam-columns, shear walls, and structural systems are covered for each material. Gravity, wind, snow, and seismic loads are calculated and utilized for design. Connection design and advanced seismic analysis principles are introduced. Prerequisite: CEEN314 or equivalent. 3 hours lecture; 3 semester hours. Spring odd years.

**CEEN543. CONCRETE BRIDGE DESIGN BASED ON THE AASHTO LRFD SPECIFICATIONS. 3.0 Semester Hrs.**

This course presents the fundamentals of concrete bridge analysis and design including conceptual design, superstructure analysis, AASHTO-LRFD bridge specifications, flat slab bridge design, and pre-stressed concrete bridge design. The course is presented through the complete design of the superstructure of an example bridges. At the conclusion of the course, students will be able to analyze and design simple, but complete concrete bridge superstructures. Prerequisites: CEEN445, Design of Reinforced Concrete Structure. 3 hours lecture; 3 semester hours.

**CEEN544. STRUCTURAL PRESERVATION OF EXISTING AND HISTORIC BUILDINGS. 3.0 Semester Hrs.**

(I, II) A broad discussion of historic structural systems in the United States, including stone and brick masonry, terra cotta, timber, cast and wrought iron, early steel, and early concrete. Combines research of historic manuals with contemporary analysis. Introduces nondestructive tests for historic structures. Enables prediction of deterioration mechanisms and structural deficiencies. Synthesizes structural retrofit solutions with preservation philosophy and current building codes. Emphasizes the engineer?s role in stewardship of historic buildings. Prerequisites: CEEN443 and CEEN445. 3 hours lecture and discussion; 3 semester hours.

**CEEN545. STEEL BRIDGE DESIGN. 3.0 Semester Hrs.**

(I, II, S) Students are introduced to, and will develop an understanding of, the theory, analysis, and AASHTO code requirements for the design of steel bridge superstructures. The students will become familiar with bridge types, required loadings, composite action, plate girder design, and the Load and Resistance Factor Design method. The students will recognize the design requirements for a steel bridge superstructure and perform calculations for member loads and the loadings it transfers to the substructure. Prerequisites: CEEN443. 3 hours lecture; 3 semester hours.

**CEEN546. STATISTICAL METHODS FOR RELIABILITY AND ENGINEERING DESIGN. 3.0 Semester Hrs.**
(I, II, S) The course will introduce methods and principles that help quantifying the effects of uncertainty in the performance prediction of civil infrastructure systems. Students will learn to apply quantitative risk analysis and modeling approaches relevant to design problems in civil engineering. The course emphasizes that the systematic treatment of uncertainty and risk quantification are essential for adequate engineering planning, design, and operation of systems. The statistical approaches fundamental to engineering design and theory of reliability in structural and underground infrastructure design will be the focus of the course and examples. 3 hours lecture; 3 semester hours.

**CEEN550. PRINCIPLES OF ENVIRONMENTAL CHEMISTRY. 3.0 Semester Hrs.**
This course provides an introduction to chemical equilibria in natural waters and engineered systems. Topics covered include chemical thermodynamics and kinetics, acid/base chemistry, open and closed carbonate systems, precipitation reactions, coordination chemistry, adsorption and redox reactions. Prerequisites: none. 3 hours lecture; 3 semester hours.

**CEEN551. ENVIRONMENTAL ORGANIC CHEMISTRY. 3.0 Semester Hrs.**
A study of the chemical and physical interactions which determine the fate, transport and interactions of organic chemicals in aquatic systems, with emphasis on chemical transformations of anthropogenic organic contaminants. Prerequisites: A course in organic chemistry and CHGN503, Advanced Physical Chemistry or its equivalent. Offered in alternate years. 3 hours lecture; 3 semester hours.

**CEEN555. LIMNOLOGY. 3.0 Semester Hrs.**
This course covers the natural chemistry, physics, and biology of lakes as well as some basic principles concerning contamination of such water bodies. Topics include heat budgets, water circulation and dispersal, sedimentation processes, organic compounds and their transformations, radionuclide limnochronology, redox reactions, metals and other major ions, the carbon dioxide system, oxygen, nutrients; planktonic, benthic and other communities, light in water and lake modeling. Prerequisite: none. 3 hours lecture; 3 semester hours.

**CEEN556. MINING AND THE ENVIRONMENT. 3.0 Semester Hrs.**
The course will cover many of the environmental problems and solutions associated with each aspect of mining and ore dressing processes. Mining is a complicated process that differs according to the type of mineral sought. The mining process can be divided into four categories: Site Development; Extraction; Processing; Site Closure. Procedures for hard rock metals mining; coal mining; underground and surface mining; and in situ mining will be covered in relation to environmental impacts. Beneficiation, or purification of metals will be discussed, with cyanide and gold topics emphasized. Site closure will be focused on; stabilization of slopes; process area cleanup; and protection of surface and ground water. After discussions of the mining and beneficiation processes themselves, we will look at conventional and innovative measures to mitigate or reduce environmental impact.

**CEEN560. MOLECULAR MICROBIAL ECOLOGY AND THE ENVIRONMENT. 3.0 Semester Hrs.**
This course explores the diversity of microbiota in a few of the countless environments of our planet. Topics include microbial ecology (from a molecular perspective), microbial metabolism, pathogens, extreme environments, engineered systems, oxidation / reduction of metals, bioremediation of both organics and inorganics, microbial diversity, phylogenetics, analytical tools and bioinformatics. The course has an integrated laboratory component for applied molecular microbial ecology to learn microscopy, DNA extraction, PCR, gel electrophoresis, cloning, sequencing, data analysis and bioinformatic applications. Prerequisite: College Biology and/or CHGC562, CHGC563 or equivalent and enrollment in the ESE graduate program. 3 hours lecture, some field trips; 3 semester hours.

**CEEN562. ENVIRONMENTAL GEOMICROBIOLOGY. 3.0 Semester Hrs.**
(II) This course explores the functional activities and biological significance of microorganisms in geological and engineered systems with a focus on implications to water resources. Topics include: microorganisms as geochemical agents of change, mechanisms and thermodynamics of microbial respiration, applications of analytical, material science and molecular biology tools to the field, and the impact of microbes on the fate and transport of problematic water pollutants. Emphasis will be placed on critical analysis and communication of peer-reviewed literature on these topics. 3 hours lecture and discussion; 3 semester hours.

**CEEN564. ENVIRONMENTAL TOXICOLOGY. 3.0 Semester Hrs.**
This course provides an introduction to general concepts of ecology, biochemistry, and toxicology. The introductory material will provide a foundation for understanding why, and to what extent, a variety of products and by-products of advanced industrialized societies are toxic. Classes of substances to be examined include metals, coal, petroleum products, organic compounds, pesticides, radioactive materials, and others. Prerequisite: none. 3 hours lecture; 3 semester hours.

**CEEN566. MICROBIAL PROCESSES, ANALYSIS AND MODELING. 3.0 Semester Hrs.**
Microorganisms facilitate the transformation of many organic and inorganic constituents. Tools for the quantitative analysis of microbial processes in natural and engineered systems will be presented. Stoichiometries, energetics, mass balances and kinetic descriptions of relevant microbial processes allow the development of models for specific microbial systems. Simple analytical models and complex models that require computational solutions will be presented. Systems analyzed include suspended growth and attached growth reactors for municipal and industrial wastewater treatment as well as in-stu bioremediation and bioenergy systems. 3 hours lecture; 3 semester hours.

**CEEN570. WATER AND WASTEWATER TREATMENT. 3.0 Semester Hrs.**
Unit operations and processes in environmental engineering are discussed in this course, including physical, chemical, and biological treatment processes for water and wastewater. Treatment objectives, process theory, and practice are considered in detail. Prerequisites: none. 3 hours lecture; 3 semester hours.

**CEEN571. ADVANCED WATER TREATMENT ENGINEERING AND WATER REUSE. 3.0 Semester Hrs.**

This course presents issues relating to theory, design, and operation of advanced water and wastewater treatment unit processes and water reuse systems. Topics include granular activated carbon (GAC), advanced oxidation processes (O3/H2O2), UV disinfection, pressure-driven, current-driven, and osmotic-driven membranes (MF, UF, NF, RO, electrodialysis, and forward osmosis), and natural systems such as riverbank filtration (RBF) and soil-aquifer treatment (SAT). The course is augmented by CEEN571L offering hands-on experience using bench- and pilot-scale unit operations. Prerequisite: CEEN470 or CEEN471 or CEEN570 or CEEN572. 3 hours lecture; 3 semester hours.

**CEEN571L. ADVANCED WATER TREATMENT ENGINEERING AND WATER REUSE - LABORATORY. 1.0 Semester Hr.**

This course provides hands-on experience using bench- and pilotscale unit operations and computer exercises using state-ofthe- art software packages to design advanced water treatment unit processes. Topics include adsorption processes onto powdered and granular activated carbon, low-pressure membrane processes (microfiltration, ultrafiltration), and highpressure and current-driven membrane processes (nanofiltration, reverse osmosis, and electrodialysis). The course is a highly recommended component of CEEN571 and meets 5 - 6 times during the semester to support the work in CEEN571. Co- or Pre-requisite: CEEN571. 1 semester hour.

**CEEN572. ENVIRONMENTAL ENGINEERING PILOT PLANT LABORATORY. 4.0 Semester Hrs.**

This course provides an introduction to bench and pilot-scale experimental methods used in environmental engineering. Unit operations associated with water and wastewater treatment for real-world treatment problems are emphasized, including multi-media filtration, oxidation processes, membrane treatment, and disinfection processes. Investigations typically include: process assessment, design and completion of bench- and pilot-scale experiments, establishment of analytical methods for process control, data assessment, upscaling and cost estimation, and project report writing. Projects are conducted both at CSM and at the City of Golden Water Treatment Pilot Plant Laboratory. Prerequisites: CEEN550 and CEEN570. 6 hours laboratory; 4 semester hours.

**CEEN573. RECLAMATION OF DISTURBED LANDS. 3.0 Semester Hrs.**

Basic principles and practices in reclaiming disturbed lands are considered in this course, which includes an overview of present legal requirements for reclamation and basic elements of the reclamation planning process. Reclamation methods, including recontouring, erosion control, soil preparation, plant establishment, seed mixtures, nursery stock, and wildlife habitat rehabilitation, will be examined. Practitioners in the field will discuss their experiences. Prerequisite: none. 3 hours lecture; 3 semester hours.

**CEEN574. SOLID WASTE MINIMIZATION AND RECYCLING. 3.0 Semester Hrs.**

This course will examine, using case studies, ways in which industry applies engineering principles to minimize waste formation and to meet solid waste recycling challenges. Both proven and emerging solutions to solid waste environmental problems, especially those associated with metals, will be discussed. Prerequisite: CEEN550. 3 hours lecture; 3 semester hours.

**CEEN575. HAZARDOUS WASTE SITE REMEDIATION. 3.0 Semester Hrs.**

This course covers remediation technologies for hazardous waste contaminated sites, including site characteristics and conceptual model development, remedial action screening processes, and technology principles and conceptual design. Institutional control, source isolation and containment, subsurface manipulation, and in situ and ex situ treatment processes will be covered, including unit operations, coupled processes, and complete systems. Case studies will be used and computerized tools for process selection and design will be employed. Prerequisite: CEEN550 and CEEN580. 3 hours lecture; 3 semester hours.

**CEEN575L. HAZARDOUS WASTE SITE REMEDIATION: TREATABILITY TESTING. 1.0 Semester Hr.**

This laboratory module is designed to provide hands-on experience with treatability testing to aid selection and design of remediation technologies for a contaminated site. The course will be comprised of laboratory exercises in Coolbaugh Hall and possibly some field site work near CSM. Pre-requisite: CEEN575. 2 hours laboratory; 1 semester hour.

**CEEN576. POLLUTION PREVENTION: FUNDAMENTALS AND PRACTICE. 3.0 Semester Hrs.**

The objective of this course is to introduce the principles of pollution prevention, environmentally benign products and processes, and manufacturing systems. The course provides a thorough foundation in pollution prevention concepts and methods. Engineers and scientists are given the tools to incorporate environmental consequences into decision-making. Sources of pollution and its consequences are detailed. Focus includes sources and minimization of industrial pollution; methodology for life-cycle assessments and developing successful pollution prevention plans; technological means for minimizing the use of water, energy, and reagents in manufacturing; and tools for achieving a sustainable society. Materials selection, process and product design, and packaging are also addressed. 3 hours lecture; 3 semester hours.

**CEEN580. CHEMICAL FATE AND TRANSPORT IN THE ENVIRONMENT. 3.0 Semester Hrs.**

(I, II, S) This course describes the environmental behavior of inorganic and organic chemicals in multimedia environments, including water, air, sediment and biota. Sources and characteristics of contaminants in the environment are discussed as broad categories, with some specific examples from various industries. Attention is focused on the persistence, reactivity, and partitioning behavior of contaminants in environmental media. Both steady and unsteady state multimedia environmental models are developed and applied to contaminated sites. The principles of contaminant transport in surface water, groundwater, and air are also introduced. The course provides students with the conceptual basis and mathematical tools for predicting the behavior of contaminants in the environment. 3 hours lecture; 3 semester hours.

**CEEN581. WATERSHED SYSTEMS MODELING. 3.0 Semester Hrs.**

Introduction to surface water modeling, including rainfall-runoff analysis, input data, uncertainty analysis, lumped and distributed modeling, parameter estimation and sensitivity analysis. Course is heavy on application of models across a range of diverse watersheds for streamflow and snowmelt predictions. In general, theoretical topics are covered in the first meeting each week, followed by hands-on application of concepts and models in the second meeting. Laptops and student Matlab licenses will be required for in-class activities. Prerequisite: none. 3 hours lecture per week; 3 semester hours.

**CEEN582. MATHEMATICAL MODELING OF ENVIRONMENTAL SYSTEMS. 3.0 Semester Hrs.**

This is an advanced graduate-level course designed to provide students with hands-on experience in developing, implementing, testing, and using mathematical models of environmental systems. The course will examine why models are needed and how they are developed, tested, and used as decision-making or policy-making tools. Typical problems associated with environmental systems, such as spatial and temporal scale effects, dimensionality, variability, uncertainty, and data insufficiency, will be addressed. The development and application of mathematical models will be illustrated using a theme topic such as Global Climate Change, In Situ Bioremediation, or Hydrologic Systems Analysis. Prerequisites: CEEN580 and knowledge of basic statistics and computer programming. 3 hours lecture; 3 semester hours.

**CEEN583. SURFACE WATER QUALITY MODELING. 3.0 Semester Hrs.**

This course will cover modeling of water flow and quality in rivers, lakes, and reservoirs. Topics will include introduction to common analytical and numerical methods used in modeling surface water flow, water quality, modeling of kinetics, discharge of waste water into surface systems, sedimentation, growth kinetics, dispersion, and biological changes in lakes and rivers. Prerequisites: CEEN480 or CEEN580 recommended. 3 hours lecture; 3 semester hours.

**CEEN584. SUBSURFACE CONTAMINANT TRANSPORT. 3.0 Semester Hrs.**

This course will investigate physical, chemical, and biological processes governing the transport and fate of contaminants in the saturated and unsaturated zones of the subsurface. Basic concepts in fluid flow, groundwater hydraulics, and transport will be introduced and studied. The theory and development of models to describe these phenomena, based on analytical and simple numerical methods, will also be discussed. Applications will include prediction of extents of contaminant migration and assessment and design of remediation schemes. Prerequisites: CEEN580. 3 hours lecture; 3 semester hours.

**CEEN585. FLUID MECHANICS FOR HYDROLOGY. 2.0 Semester Hrs.**

This class focuses on the fundamental concepts of engineering fluid mechanics as they relate to the study of hydrology. Topics include fluid statics, dynamics, continuity, energy and momentum, dimensional analysis and open channel flow.

**CEEN587. HYDROGEOCHEMICAL PROCESSES. 3.0 Semester Hrs.**

(II) Analysis of the chemistry of natural waters in the context of hydrologic systems. The course focuses on sources and dynamic behavior of common natural and anthropogenically introduced solutes of interest, their interactions with minerals, and fate and transport in subsurface and surface environments. 3 hours lecture; 3 semester hours.

**CEEN589. WATER SUSTAINABILITY AND ENERGY PRODUCTION: CURRENT SCIENCE AND PRACTICE. 1.0 Semester Hr.**

(II) This course is designed to provide students with valuable communication and professional skills while exploring in depth the topic of joint sustainability of water and unconventional petroleum energy production. A survey of current literature combined with key speakers will introduce the students to the field, while class sessions and practical exercises will help develop important communication, research, and interpersonal skills needed for future professionals. Course curriculum includes specific topics such as speaking/writing for a variety of audiences and critical thinking and analysis. This course is required for all ConocoPhillips - WE2ST Fellows, but is also open to any interested graduate students. 1 hour seminar; 1 semester hour.

**CEEN590. CIVIL ENGINEERING SEMINAR. 1.0 Semester Hr.**

(I) Introduction to contemporary and advanced methods used in engineering design. Includes, need and problem identification, methods to understand the customer, the market and the competition. Techniques to decompose design problems to identify functions. Ideation methods to produce form from function. Design for X topics. Methods for prototyping, modeling, testing and evaluation of designs. Embodiment and detailed design processes. Prerequisites: EGGN491 and EGGN492, equivalent senior design project experience or industrial design experience, graduate standing. 3 hours lecture; 3 semester hours. Taught on demand.

**CEEN592. ENVIRONMENTAL LAW. 3.0 Semester Hrs.**

Equivalent with CEEN492,PEGN530,

This is a comprehensive introduction to U.S. Environmental Law, Policy, and Practice, especially designed for the professional engineer, scientist, planner, manager, consultant, government regulator, and citizen. It will prepare the student to deal with the complex system of laws, regulations, court rulings, policies, and programs governing the environment in the USA. Course coverage includes how our legal system works, sources of environmental law, the major USEPA enforcement programs, state/local matching programs, the National Environmental Policy Act (NEPA), air and water pollution (CAA, CWA), EPA risk assessment training, toxic/hazardous substances laws (RCRA, CERCLA, EPCRA, TSCA, LUST, etc.), and a brief introduction to international environmental law. Prerequisites: none. 3 hours lecture; 3 semester hours.

**CEEN594. RISK ASSESSMENT. 3.0 Semester Hrs.**

This course evaluates the basic principles, methods, uses, and limitations of risk assessment in public and private sector decision making. Emphasis is on how risk assessments are made and how they are used in policy formation, including discussion of how risk assessments can be objectively and effectively communicated to decision makers and the public. Prerequisite: CEEN592 and one semester of statistics. 3 hours lecture; 3 semester hours.

**CEEN595. ANALYSIS OF ENVIRONMENTAL IMPACT. 3.0 Semester Hrs.**

Techniques for assessing the impact of mining and other activities on various components of the ecosystem. Training in the procedures of preparing Environmental Impact Statements. Course will include a review of pertinent laws and acts (i.e. Endangered Species Act, Coordination Act, Clean Air Act, etc.) that deal with environmental impacts. Prerequisite: none. 3 hours lecture, some field trips; 3 semester hours.

**CEEN596. ENVIRONMENTAL SCIENCE AND ENGINEERING SEMINAR. 0.0 Semester Hrs.**

Research presentations covering current research in a variety of environmental topics.

**CEEN598. SPECIAL TOPICS IN CIVIL AND ENVIRONMENTAL ENGINEERING. 6.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**CEEN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**CEEN610. INTERNATIONAL ENVIRONMENTAL LAW. 3.0 Semester Hrs.**
The course covers an introductory survey of International Environmental Law, including multi-nation treaties, regulations, policies, practices, and politics governing the global environment. It surveys the key issues of sustainable development, natural resources projects, transboundary pollution, international trade, hazardous waste, climate change, and protection of ecosystems, wildlife, and human life. New international laws are changing the rules for engineers, project managers, scientists, teachers, businesspersons, and others both in the US and abroad, and this course is especially designed to keep professionals fully, globally informed and add to their credentials for international work. Prerequisites: CEEN592. 3 hours lecture; 3 semester hours.

**CEEN611. MULTIPHASE CONTAMINANT TRANSPORT. 3.0 Semester Hrs.**
Principles of multiphase and multicomponent flow and transport are applied to contaminant transport in the unsaturated and saturated zones. Focus is on immiscible phase, dissolved phase, and vapor phase transport of low solubility organic contaminants in soils and aquifer materials. Topics discussed include: capillarity, interphase mass transfer, modeling, and remediation technologies. Prerequisites: CEEN550 or equivalent, CEEN580 or CEEN584 or equivalent. 3 hours lecture; 3 semester hours.

**CEEN698. SPECIAL TOPICS IN CIVIL AND ENVIRONMENTAL ENGINEERING. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**CEEN699. ADVANCED INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**CEEN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) GRADUATE THESIS/DISSERTATION RESEARCH CREDIT Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

## Department Head

Terri Hogue

## Professors

Junko Munakata Marr

Tzahi Cath

Linda Figueroa

D.V. Griffiths

Marte Gutierrez, James R. Paden Distinguished Chair

Christopher Higgins

Terri Hogue

Tissa Illangasekare, AMAX Distinguished Chair

Amy Landis

Ning Lu

John E. McCray

Michael Mooney, Grewcock Distinguished Chair

Kamini Singha

John R. Spear

Timothy Strathmann

## Associate Professors

Shiling Pei

Jonathan O. Sharp

## Assistant Professors

Christopher Bellona

Reza Hedayat

Lori Tunstall

## Teaching Professors

Joseph Crocker

Kristoph Kinzli

## Teaching Associate Professors

Andres Guerra

Jeffery Holley

Hongyan Liu

Alexandra Wayllace

## Teaching Assistant Professors

Chelsea Panos

Lori Tunstall

# Chemistry

## Degrees Offered

- Master of Science (Chemistry; thesis and non-thesis options)
- Doctor of Philosophy (Applied Chemistry)

## Program Description

The Department of Chemistry offers MS (thesis and non-thesis options) in Chemistry and PhD degrees in Applied Chemistry. In addition, interdisciplinary MS and PhD degrees are also offered in Geochemistry, Hydrological Sciences and Engineering, Materials Science, Nuclear Engineering, and Quantitative Biosciences and Engineering.

## Prerequisites

A candidate for an advanced degree in the Chemistry program should have completed an undergraduate program in Chemistry which is essentially equivalent to that offered by the Department of Chemistry at the Colorado School of Mines. Undergraduate deficiencies will be determined by faculty in the Department of Chemistry through interviews and/or placement examinations at the beginning of the student's first semester of graduate work.

## WICHE

All graduate degree programs in the Department of Chemistry have been admitted to the Western Regional Graduate Program (WICHE). This program allows residents of Alaska, Arizona, California, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming to register at Colorado resident tuition rates.

## Required Curriculum

## Chemistry

A student in the chemistry program, in consultation with the advisor and thesis committee, selects the program of study. Initially, before a thesis advisor and thesis committee have been chosen, the student is advised by a temporary advisor and by the Graduate Affairs Committee in the Department of Chemistry.

## MS Degree (Chemistry, thesis option)

The program of study includes coursework, research, and the preparation and oral defense of an MS thesis based on the student’s research.  The required courses are:

| | | |
|---|---|---|
| CHGN502 | ADVANCED INORGANIC CHEMISTRY | 3.0 |
| CHGN503 | ADV PHYSICAL CHEMISTRY I | 3.0 |
| CHGN505 | ADVANCED ORGANIC CHEMISTRY | 3.0 |
| CHGN507 | ADVANCED ANALYTICAL CHEMISTRY | 3.0 |
| CHGN560 | GRADUATE SEMINAR, M.S. (M.S.-level seminar ) | 1.0 |

Students should enroll in CHGN560 in the first semester of their degree program. A minimum of 36 semester hours, including at least 24 semester hours of course work, are required. At least 15 of the required 24 semester hours of course work must be taken in the Department of Chemistry at Mines. The student’s thesis committee makes decisions on transfer credit. Up to 9 semester hours of graduate courses may be transferred from other institutions, provided that those courses have not been used as credit toward a Bachelor's degree.

**Research-Intensive MS Degree:** Mines undergraduates who enter the graduate program through the combined BS/MS program may use this option (thesis-based MS) to acquire a research-intensive MS degree by minimizing the time spent on coursework. This option requires a minimum of 12 hours of coursework up to six hours of which may be double counted from the student's undergraduate studies at Mines (see below).

**MS Degree (chemistry, non-thesis option):** The non-thesis MS degree requires 30 semester hours of course credit:

| | |
|---|---|
| Course work | 24.0 |
| Independent study | 6.0 |
| Total Semester Hrs | 30.0 |

The program of study includes coursework, independent study on a topic determined by the student and the student’s faculty advisor, and the preparation of an oral presentation of a report based on the student’s independent study topic.  The required courses are:

| | | |
|---|---|---|
| CHGN502 | ADVANCED INORGANIC CHEMISTRY | 3.0 |
| CHGN503 | ADV PHYSICAL CHEMISTRY I | 3.0 |
| CHGN505 | ADVANCED ORGANIC CHEMISTRY | 3.0 |
| CHGN507 | ADVANCED ANALYTICAL CHEMISTRY | 3.0 |
| CHGN560 | GRADUATE SEMINAR, M.S. (M.S.-level seminar) | 1.0 |
| Total Semester Hrs | | 13.0 |

Students should enroll in CHGN560 in the first semester of their degree program. At least 21 of the required 30 semester hours of course work must be taken as a registered master’s degree student at Mines. The student’s committee makes decisions on courses to be taken, transfer credit, and examines the student’s written report. Up to 9 semester hours of graduate courses may be transferred into the degree program, provided that those courses have not been used as credit toward a Bachelor's degree.

## Mines’ Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines’ combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any courses that count towards the graduate degree requirements as either "Required Coursework" or "Elective Coursework", as defined below, may be used for the purposes of double counting at the discretion of the advisor (MS Non-Thesis) or thesis committee (MS Thesis or PhD). These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit.

## PhD Degree (Applied Chemistry)

The program of study for the PhD degree in Applied Chemistry includes coursework, a comprehensive examination, a thesis proposal, research, and the preparation and oral defense of a PhD thesis based on the student's research.

*Coursework*. The required courses are:

| | | |
|---|---|---|
| CHGN502 | ADVANCED INORGANIC CHEMISTRY | 3.0 |
| CHGN503 | ADV PHYSICAL CHEMISTRY I | 3.0 |
| CHGN505 | ADVANCED ORGANIC CHEMISTRY | 3.0 |
| CHGN507 | ADVANCED ANALYTICAL CHEMISTRY | 3.0 |
| CHGN560 | GRADUATE SEMINAR, M.S. (M.S.-level seminar) | 1.0 |
| CHGN660 | GRADUATE SEMINAR, Ph.D. (Ph.D.-level seminar) | 1.0 |
| Total Semester Hrs | | 14.0 |

The total hours of course work required for the PhD degree is determined on an individual basis by the student's thesis committee. Up to 24 semester hours of graduate-level course work may be transferred from other institutions toward the PhD degree provided that those courses have not been used by the student toward a Bachelor's degree. Up to 36 hours of credit may be transferred if the student has completed a Master's degree. The student's thesis committee may set additional course requirements and will make decisions on requests for transfer credit.

*Seminar requirement*. Students should enroll in CHGN560 in the first semester of their degree program. The CHGN560 seminar must be completed no later than the end of the student's second year of graduate studies at Mines. The semester after completion of the CHGN560 seminar, students must enroll in CHGN660. The CHGN660 seminar must include detailed research findings and interpretation of the student's PhD thesis research and must be presented close to, but before, the student's oral defense of the thesis.

*Comprehensive examination*. The comprehensive examination comprises a written literature review of the student's field of research, an oral presentation and defense of the literature review before the student's thesis committee, and oral answers to questions posed by the thesis committee during the defense. The literature review must be completed prior to the end of the student's second year of graduate studies. A student's thesis committee may, at its discretion, require additional components to the comprehensive examination process.

*Thesis proposal.* The thesis proposal should include a statement of the hypotheses, goals and objectives of the proposed research, the significance and novelty of the research in the context of previously published studies, a description of methodology and results to date, a timeline with milestones, and a description of how the student has contributed to the creation or direction of the project. The thesis proposal must be orally defended before the student's thesis committee prior to completion of the student's third year of studies.

## Geochemistry

Please see the Geochemistry (http://catalog.mines.edu/graduate/programs/interdisciplinaryprograms/geochemistry/) section of this bulletin for more information.

## Fields of Research

**Analytical and bioanalytical chemistry.** Separation and characterization techniques for polymers, biopolymers, nano-particles and natural colloids. Biodetection of pathogens. Advanced separations for nuclear fuel cycle. Instrumental analysis.

**Energy sciences.** Alternative fuels. New materials and technologies for solar energy capture, conversion, and storage. Electrochemistry and Radiochemistry. Energy materials from chemical wastes.

**Environmental chemistry.** Detection and fate of anthropogenic contaminants in water, soil, and air. Acid mine drainage. Ecotoxicology. Environmental photochemistry. Cleaning of industrial pollutants.

**Geochemistry and biogeochemistry.** Microbial and chemical processes in global climate change, biomineralization, metal cycling, medical and archeological geochemistry, humic substances.

**Inorganic Chemistry.** Synthesis, characterization, and applications of metal, metal oxide, and semiconductor nanomaterials.

**Nanoscale materials.** Design, synthesis and characterization of new materials for catalysis, energy sciences, spectroscopic applications and drug delivery. Environmental fate of nanoparticles.

**Organic Chemistry.** Polymer design, synthesis and characterization. Catalysis. Alternative fuels.

**Physical and Computational Chemistry.** Computational chemistry for polymer design, clathrate hydrates, porous media, molecular simulation, energy sciences, biophysical chemistry, rational design of molecular materials, photochemical processes and excited state dynamics, and materials research. Surface-enhanced Raman spectroscopy. Laser Flash Photolysis.

**Polymers.** New techniques for controlling polymer architecture and composition. Theory and simulation. Separation and characterization.

## Courses

**CHGN502. ADVANCED INORGANIC CHEMISTRY. 3.0 Semester Hrs.**
Detailed examination of concepts such as molecular symmetry, group theory, molecular orbital theory, ligand field theory, and crystal field theory. Additional topics include spectroscopy, inorganic reaction mechanisms, and organometallic chemistry.

**CHGN503. ADV PHYSICAL CHEMISTRY I. 3.0 Semester Hrs.**
(II) Quantum chemistry of classical systems. Principles of chemical thermodynamics. Statistical mechanics with statistical calculation of thermodynamic properties. Theories of chemical kinetics. 3 hours lecture; 3 semester hours. Prerequisite: none.

**CHGN505. ADVANCED ORGANIC CHEMISTRY. 3.0 Semester Hrs.**
Detailed discussion of the more important mechanisms of organic reaction. Structural effects and reactivity. The application of reaction mechanisms to synthesis and structure proof. Prerequisite: none. 3 hours lecture; 3 semester hours.

**CHGN507. ADVANCED ANALYTICAL CHEMISTRY. 3.0 Semester Hrs.**
(I) Review of fundamentals of analytical chemistry. Literature of analytical chemistry and statistical treatment of data. Manipulation of real substances; sampling, storage, decomposition or dissolution, and analysis. Detailed treatment of chemical equilibrium as related to precipitation, acid-base, complexation and redox titrations. Potentiometry and UV-visible absorption spectrophotometry. Prerequisite: none. 3 hours lecture; 3 semester hours.

**CHGN508. ANALYTICAL SPECTROSCOPY. 3.0 Semester Hrs.**
(II) Detailed study of classical and modern spectroscopic methods; emphasis on instrumentation and application to analytical chemistry problems. Topics include: UV-visible spectroscopy, infrared spectroscopy, fluorescence and phosphorescence, Raman spectroscopy, arc and spark emission spectroscopy, flame methods, nephelometry and turbidimetry, reflectance methods, Fourier transform methods in spectroscopy, photoacoustic spectroscopy, rapid-scanning spectroscopy. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered alternate years.

**CHGN510. CHEMICAL SEPARATIONS. 3.0 Semester Hrs.**
(II) Survey of separation methods, thermodynamics of phase equilibria, thermodynamics of liquid-liquid partitioning, various types of chromatography, ion exchange, electrophoresis, zone refining, use of inclusion compounds for separation, application of separation technology for determining physical constants, e.g., stability constants of complexes. Prerequisite: CHGN507. 3 hours lecture; 3 semester hours. Offered alternate years.

**CHGN511. APPLIED RADIOCHEMISTRY. 3.0 Semester Hrs.**
(II) The Applied Radiochemistry course is designed for those who have a budding interest radiochemistry and its applications. A brief overview of radioactivity and general chemistry will be provided in the first three weeks of the course. Follow-on weeks will feature segments focusing on the radiochemistry in the nuclear fuel cycle, radioisotope production, nuclear forensics and the environment. Prerequisites: CHGN121/ CHGN122. 3 hours lecture and discussion; 3 semester hours.

**CHGN512. COLLOID AND SURFACE CHEMISTRY. 3.0 Semester Hrs.**
Introduction to colloid systems, capillarity, surface tension and contact angle, adsorption from solution, micelles and micro - emulsions, the solid/gas interface, surface analytical techniques, van der Waal forces, electrical properties and colloid stability, some specific colloid systems (clays, foams and emulsions) will be introduced.

**CHGN515. CHEMICAL BONDING IN MATERIALS. 3.0 Semester Hrs.**
(I) Introduction to chemical bonding theories and calculations and their applications to solids of interest to materials science. The relationship between a material?s properties and the bonding of its atoms will be examined for a variety of materials. Includes an introduction to organic polymers. Computer programs will be used for calculating bonding parameters. Prerequisite: none. 3 hours lecture; 3 semester hours.

**CHGN523. SOLID STATE CHEMISTRY. 3.0 Semester Hrs.**
(I) Dependence of properties of solids on chemical bonding and structure; principles of crystal growth, crystal imperfections, reactions and diffusion in solids, and the theory of conductors and semiconductors. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered alternate years.

**CHGN536. ADVANCED POLYMER SYNTHESIS. 3.0 Semester Hrs.**
(II) An advanced course in the synthesis of macromolecules. Various methods of polymerization will be discussed with an emphasis on the specifics concerning the syntheses of different classes of organic and inorganic polymers. Prerequisite: CHGN430, ChEN415, MLGN530. 3 hours lecture, 3 semester hours.

**CHGN538. ORGANIC SEMICONDUCTORS: NEW TECHNOLOGIES FOR EMERGING APPLICATIONS. 3.0 Semester Hrs.**
(II) Organic Light Emitting Diodes (OLEDs) is a display technology that can be found in many commercial products such as the smartphones and tablets. This technology was on the R&D bench-top just 10 years ago and has now reached high volume manufacturing. Other related technologies like organic photovoltaics (OPV) and organic thin film transistors (OTFT) are now on the heels of commercialization as well. This course will provide an overview on how this meteoric rise from bench-top to commercial products occurred as well as the design, synthesis and uses of conjugated organic small molecules, oligomers and polymers in applications such as OLEDs (for flat panel displays and lighting), OPV, OTFT, and sensors. Additional topics to be covered are factors governing the materials physical properties and structure-property relationship in electronic device applications. The prospect of using low cost printing techniques such as inkjet, screen, and gravure printing in the fabrication of roll-to-roll organic based devices will be discussed. Encapsulation, lifetime and reliability issues will also be presented. Prerequisites: Organic Chemistry 1 & 2 are encouraged. 3 hours lecture; 3 semester hours.

**CHGN540. PROFESSIONAL SKILLS FOR CHEMICAL SCIENTISTS. 1.0 Semester Hr.**
The goal of this course is to provide students a set of skills that are complementary to their core education. The contents of this course cover a broad range of topics that will provide the participants a perspective on careers in science and the skill sets necessary to be successful in each. These skills are in line with the latest recommendations of the American Chemical Society (ACS) and CSM educational goals. In particular, the 2013 ACS Presidential Commission Report on Graduate Education in the Chemical Sciences presents a platform for educational reform that includes a focus on multi-level (from general public to specialists) and multi-platform communication (formal and informal, written, oral), an understanding of the global chemical enterprise and the career possibilities within each, an understanding of networking and collaboration, etc. 1 hour lecture; 1 semester hour.

**CHGN555. POLYMER AND COMPLEX FLUIDS COLLOQUIUM. 1.0 Semester Hr.**
Equivalent with CBEN555,MLGN555,
The Polymer and Complex Fluids Group at the Colorado School of Mines combines expertise in the areas of flow and field based transport, intelligent design and synthesis as well as nanomaterials and nanotechnology. A wide range of research tools employed by the group includes characterization using rheology, scattering, microscopy, microfluidics and separations, synthesis of novel macromolecules as well as theory and simulation involving molecular dynamics and Monte Carlo approaches. The course will provide a mechanism for collaboration between faculty and students in this research area by providing presentations on topics including the expertise of the group and unpublished, ongoing campus research. Prerequisites: none. 1 hour lecture; 1 semester hour. Repeatable for credit to a maximum of 3 hours.

**CHGN560. GRADUATE SEMINAR, M.S.. 1.0 Semester Hr.**
(I, II) Required for all candidates for the M.S. and Ph.D. degrees in chemistry and geochemistry. M.S. students must register for the course during each semester of residency. Ph.D. students must register each semester until a grade is received satisfying the prerequisites for CHGN660. Presentation of a graded non-thesis seminar and attendance at all departmental seminars are required. Prerequisite: Graduate student status. 1 semester hour.

**CHGN580. STRUCTURE OF MATERIALS. 3.0 Semester Hrs.**
(II) Application of X-ray diffraction techniques for crystal and molecular structure determination of minerals, inorganic and organometallic compounds. Topics include the heavy atom method, data collection by moving film techniques and by diffractometers, Fourier methods, interpretation of Patterson maps, refinement methods, direct methods. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered alternate years.

**CHGN581. ELECTROCHEMISTRY. 3.0 Semester Hrs.**
(I) Introduction to theory and practice of electrochemistry. Electrode potentials, reversible and irreversible cells, activity concept. Interionic attraction theory, proton transfer theory of acids and bases, mechanisms and fates of electrode reactions. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered alternate years.

**CHGN583. PRINCIPLES AND APPLICATIONS OF SURFACE ANALYSIS TECHNIQUES. 3.0 Semester Hrs.**
(II) Instrumental techniques for the characterization of surfaces of solid materials; Applications of such techniques to polymers, corrosion, metallurgy, adhesion science, microelectronics. Methods of analysis discussed: x-ray photoelectron spectroscopy (XPS), auger electron spectroscopy (AES), ion scattering spectroscopy (ISS), secondary ion mass spectrometry (SIMS), Rutherford backscattering (RBS), scanning and transmission electron microscopy (SEM, TEM), energy and wavelength dispersive x-ray analysis; principles of these methods, quantification, instrumentation, sample preparation. 3 hours lecture; 3 semester hours. Prerequisite: B.S. in Metallurgy, Chemistry, Chemical Engineering, Physics, or consent of instructor.

**CHGN584. FUNDAMENTALS OF CATALYSIS. 3.0 Semester Hrs.**
(II) The basic principles involved in the preparation, characterization, testing and theory of heterogeneous and homo geneous catalysts are discussed. Topics include chemisorption, adsorption isotherms, diffusion, surface kinetics, promoters, poisons, catalyst theory and design, acid base catalysis and soluble transition metal complexes. Examples of important industrial applications are given. Prerequisite: CHGN222. 3 hours lecture; 3 semester hours.

**CHGN585. CHEMICAL KINETICS. 3.0 Semester Hrs.**
(II) Study of kinetic phenomena in chemical systems. Attention devoted to various theoretical approaches. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered alternate years.

**CHGN598. SPECIAL TOPICS IN CHEMISTRY. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**CHGN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**CHGN625. MOLECULAR SIMULATION. 3.0 Semester Hrs.**
Principles and practice of modern computer simulation techniques used to understand solids, liquids, and gases. Review of the statistical foundation of thermodynamics followed by indepth discussion of Monte Carlo and Molecular Dynamics techniques. Discussion of intermolecular potentials, extended ensembles, and mathematical algorithms used in molecular simulations. Prerequisites: ChEN509 or equivalent, ChEN610 or equivalent recommended. 3 hours lecture; 3 semester hours.

**CHGN660. GRADUATE SEMINAR, Ph.D.. 1.0 Semester Hr.**
(I, II) Required of all candidates for the doctoral degree in chemistry or geochemistry. Students must register for this course each semester after completing CHGN560. Presentation of a graded nonthesis seminar and attendance at all department seminars are required. Prerequisite: CHGN560 or equivalent. 1 semester hour.

**CHGN698. SPECIAL TOPICS IN CHEMISTRY. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**CHGN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**CHGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

## Professors

Mark E. Eberhart

Thomas Gennett, Department Head

Richard C. Holz

Mark P. Jensen, Grandey University Chair in Nuclear Science & Engineering

Daniel M. Knauss

Matthew C. Posewitz

James F. Ranville

Ryan M. Richards

Alan S. Sellinger

Bettina M. Voelker

Kim R. Williams

David T. Wu

## Associate Professors

Judith Klein-Seetharaman

Jenifer C. Shafer

Brian G. Trewyn

## Assistant Professors

Dylan Domaille

C. Michael McGuirk

Christine Morrison

Svitlana Pylypenko

Shubham Vyas

## Teaching Professors

Renee L. Falconer, Assistant Department Head

Mark R. Seger

## Teaching Associate Professors

Allison G. Caster

Angela Sower

## Teaching Assistant Professors

Amanda Jameer

Jonathan Miorelli

## Research Assistant Professors

Jessica Jackson

Yuan Yang

## Joint Appointees

Michael Guarnieri

Jesse Hensley

Seonah Kim

Calvin Mukarakate

Bryan Pivovar

David Robichaud

Daniel Ruddy

Robert S. Rundburg

Derek Vardon

## Affiliated Faculty

Gayle Bentley

Joseph Meyer

Kathleen Smith

## Professor Emeriti

Scott W. Cowley

Stephen R. Daniel

Dean W. Dickerhoof

Kenneth W. Edwards

Ronald W. Klusman

Donald Langmuir

Donald L. Macalady

Patrick MacCarthy

Michael J. Pavelich

E. Craig Simmons

Kent J. Voorhees

Thomas R. Wildeman

John T. Williams

# Computer Science

## Degrees Offered

- Master of Science (Computer Science)
- Doctor of Philosophy (Computer Science)
- Graduate Certificate in CyberSecurity for Cyber Physical Systems
- Post-Baccalaureate Professional Computer Science Certificate

## Program Overview

The Computer Science Department offers two online Certificates (they are currently pending approval from the Higher Learning Commission), as well as the degrees Master of Science and Doctor of Philosophy in Computer Science. These degree programs demand academic rigor and depth yet also address real-world problems.

The Department's research falls into three core fields of Computer Science: (1) Systems (e.g., High Performance Computing, Programming Languages, Cybersecurity, and Networking); (2) Intelligence (e.g., Robotics and Machine Learning); and (3) Algorithms (e.g., Classical, Learning, and Game-Theoretic). Some faculty also do research in CS Education and, in many cases, individual research projects encompass more than one research area.

## Research Areas:

**ALGORITHMIC ROBOTICS**
An interdisciplinary research area drawing from traditional computer science, engineering, and cognitive science. Research themes include artificial intelligence, human-robot interaction, and augmented reality, focusing on integrating computer vision and perception, learning and adaptation, natural language understanding and generation, and decision making into unified robot systems.

**APPLIED ALGORITHMS**
Research in Applied Algorithms and Data Structures combines classical algorithms research (characterized by the development of elegant algorithms and data structures accompanied by theory that provides mathematical guarantees about performance) and applications research (consisting of the actual development of software accompanied by empirical evaluations on appropriate benchmarks). Applications include cheminformatics and material science, crowdsourcing, data analytics, mobile computing, networking, security and privacy, the smart grid and VLSI design automation.

**AUGMENTED REALITY**
This area focuses on sensing information about the real world, augmenting visualization of reality by overlaying virtual information on the real world, and enabling user to interact with and digitally manipulate the information.

**CS FOR ALL: COMPUTER SCIENCE EDUCATION**
This area encompasses research on STEM recruitment and diversity, K-12 computing education, and computing/engineering education at the university level. Current projects include an on-campus computing outreach program tailored for girls across a broad age range; professional development opportunities for CS high school teachers; and incorporating ethics into core and elective computing courses.

**CYBERSECURITY**
Research includes usable security and privacy in web/mobile/cloud/cyber-physical/IoT/AI systems, vulnerability measurement and analysis, and cybersecurity education.

**HIGH PERFORMANCE COMPUTING**
Our high performance computing research focuses on using compiler and runtime techniques to optimize Big Data and machine learning applications on heterogeneous systems.

**MACHINE LEARNING**
Includes research in developing mathematical foundations and algorithm design needed for computers to learn. Focus areas include fundamental research in machine learning and numerical methods, as well as developing novel algorithms for bioinformatics, data mining, computer vision, biomedical image analysis, parallel computing, natural language processing, and data privacy.

**NETWORKED SYSTEMS**
Research aims to enable emerging wireless applications via networks and systems support, ranging from hardware design to algorithms development and software integration, from credible simulations to actual system deployment and testing.

## PROGRAM DETAILS

The Computer Science Department offers a variety of programs:

There are two Certificate programs; one is a Post-Baccalaureate Professional Computer Science Certificate and the second is a Graduate Certificate in CyberSecurity for Cyber Physical Systems. Both are offered online.

We also offer the degrees Master of Science and Doctor of Philosophy in Computer Science. The master's program is designed to prepare candidates for careers in industry or government or for further study at the PhD level; both thesis and non-thesis options are available. The PhD degree program is sufficiently flexible to prepare candidates for careers in industry, government, or academia.

*Combined Program:* The CS Department also offers combined BS/MS degree programs. These programs offer an expedited graduate school application process and allow students to begin graduate coursework while still finishing their undergraduate degree requirements.

## Admission PREREQUISITES

### BS+MS Combined

Current Mines undergraduate students are encouraged to apply for the combined program once they have taken five or more Computer Science classes at Mines (classes transferred from other universities will not be considered). This requirement may be met by any 200-level or above course with a CSCI prefix (e.g., CSCI261, CSCI306, CSCI442, etc.), excluding CSCI274, CSCI370, CSCI499.

Students should have an overall GPA of at least 2.5 and a GPA of 3.2 for courses in the major. The calculation of GPA in the major will be based on *all* 200-level or above CSCI courses except those excluded above (i.e., CSCI274, CSCI370 and CSCI499). If a course is taken multiple times, all of the grades will be included into the GPA calculation. Interested students with a lower GPA must include in their statement of goals/personal statement a section explaining why they should be admitted to the program.

## POST-BACCALAUREATE PROFESSIONAL COMPUTER SCIENCE CERTIFICATE

The minimum requirements for admission to the Post-Baccalaureate Professional Computer Science Certificate are:

- Applicants must have a Bachelor's degree, or equivalent, from an accredited institution in an area of study that is not Computer Science.

## GRADUATE CERTIFICATE IN CYBERSECURITY FOR CYBER PHYSICAL SYSTEMS

The minimum requirements for admission to the Graduate Certificate in CyberSecurity for Cyber Physical Systems are:

- Undergraduate-level knowledge on data structures, computer organization, algorithms, and operating systems.
- Undergraduate-level knowledge on statistics and discrete mathematics.
- Undergraduate-level skills on the Linux operating system and shell scripts.
- Undergraduate-level programming skills in languages such as C, C++, Python, Java, JavaScript, and HTML/CSS.

## MASTERS AND PHD

The minimum requirements for admission to the MS and Ph.D degrees in Computer Science are:

- Applicants must have a Bachelor's degree, or equivalent, from an accredited institution with a grade-point average of 3.0 or better on a 4.0 scale.
- Students are expected to have completed two semesters of calculus, along with courses in object-oriented programming and data structures, and upper level courses in at least three of the following areas: software engineering, numerical analysis, computer architecture, principles of programming languages, analysis of algorithms, and operating systems.
- Competitive Graduate Record Examination scores (verbal reasoning, quantitative reasoning, and analytical writing), with a minimum quantitative reasoning score of 151 or higher (or 650 on the old scale). Applicants who have graduated with a Math, engineering, or science degree from Mines within the past five years are not required to submit GRE scores.
- TOEFL score of 79 or higher (or 550 for the paper-based test or 213 for the computer-based test) for applicants whose native language is not English. In lieu of a TOEFL score, and IELTS score of 6.5 or higher will be accepted.
- For the PhD program, prior research experience is desired but not required.

*Admitted Students:* The CS Department Graduate Committee may require that an admitted student take undergraduate remedial coursework to overcome technical deficiencies. The committee will decide whether to recommend regular or provisional admission.

*Transfer Courses:* Graduate level courses taken at other universities for which a grade equivalent to a "B" or better was received will be considered for transfer credit with approval of the Advisor and/or Thesis Committee, and CS Department Head, as appropriate. Transfer credits must not have been used as credit toward a Bachelor degree. For the MS degree, no more than nine credits may transfer. For the PhD degree, up to 24 credit hours may be transferred. In lieu of transfer credit for individual courses, students who enter the PhD program with a thesis-based master's degree from another institution may transfer up to 36 hours in recognition of the course work and research completed for that degree.

*400-level Courses:* As stipulated by the Mines Graduate School, students may apply toward graduate degree requirements a maximum of nine (9.0) semester hours of department-approved 400-level course work.

*Advisor and Thesis Committee:* Students must have an Advisor from the CS faculty to direct and monitor their academic plan, research, and independent studies. Advisors must be full-time permanent members of the faculty. In this context, full-time permanent members of the faculty are those that hold the rank of professor, associate professor, assistant professor, research professor, associate research professor or assistant research professor. Upon approval by the Graduate Dean, adjunct faculty, teaching faculty, visiting professors, emeritus professors and off-campus representatives may be designated additional co-advisors. A list of CS faculty by rank is available in the faculty tab of the catalog.

Master of Science (thesis option) students in CS must have at least three members on their Thesis Committee; the Advisor and one other member must be permanent faculty in the CS Department. CS PhD Thesis Committees must have at least four members; the Advisor/co-advisor and two additional members must be permanent faculty in the CS Department, and one member must be outside the departmental faculty and serving as chair of the committee. Students who choose to have a minor program must select a representative from the minor area of study to serve on the Thesis Committee.

*Degree Audit and Admission to Candidacy:* Master students must complete the Degree Audit form (http://gradschool.mines.edu/Degree-Audit/)by the posted deadline. PhD students need to submit the Degree Audit form (http://gradschool.mines.edu/Degree-Audit/) by the posted deadline and need to submit the Admission to Candidacy form (https://inside.mines.edu/GS-Candidacy-Addendum/) two weeks prior to census day of the semester in which they want to be considered eligible for reduced registration.

*Time Limit:* As stipulated by the Mines Graduate School, a candidate for a Masters degree must complete all requirements for the degree within five years of the date of admission into the degree program. A candidate for a doctoral degree must complete all requirements for the degree within nine years of the date of admission into the degree program.

## PROGRAM REQUIREMENTS

### Mines' Combined Undergraduate/Graduate Degree Program

Students enrolled in the Department of Computer Science Combined Undergraduate/Graduate Program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Under the Combined Program, students may count two courses (CSCI406, and/or CSCI442 along with one additional CSCI 400-level course) towards both the undergraduate degree and the graduate degree. These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit. One additional 400-level course may be counted toward the graduate degree, if the course is not counted towards the undergraduate degree. Students selecting the Thesis option will be required to complete 21 hours of coursework and a thesis (9 credit hours). Students selecting the Non-Thesis option will be required to complete 30 credit hours of coursework. There are two required graduate-level courses: CSCI564 (https://catalog.mines.edu/search/?P=CSCI564/) (Advanced Architecture) and CSCI561 (https://catalog.mines.edu/search/?P=CSCI561/)(Theory of Computation). The remaining courses are all electives except for the double counted courses.

Current Mines undergraduate students are encouraged to apply for the combined program once they have taken five or more Computer Science classes at Mines (classes transferred from other universities will not be considered). This requirement may be met by any 200-level or above course with a CSCI prefix (e.g., CSCI261, CSCI306, CSCI442, etc.), excluding CSCI274, CSCI370, CSCI499. Students should have an overall GPA of at least 2.5 and a GPA of 3.2 for courses in the major. The calculation of GPA in the major will be based on all 200-level or above CSCI courses except those excluded above (i.e., CSCI274, CSCI370 and CSCI499). If a course is taken multiple times, all of the grades will be included into the GPA calculation. Interested students with a lower GPA must include in their statement of goals/personal statement a section explaining why they should be admitted to the program.

## Master of Science - Computer Science

The MS degree in Computer Science (Thesis or Non-Thesis option) requires 30 credit hours. Requirements for the thesis MS are 21 hours of coursework plus 9 hours of thesis credit leading to an acceptable Master's thesis; thesis students are encouraged to find a thesis advisor and form a Thesis Committee by the end of the first year. The non-thesis option consists of two tracks: a Project Track and a Coursework Track. Requirements for the Project Track are 24 hours of coursework plus 6 hours of project credit; requirements for the Coursework Track are 30 hours of coursework. All MS Non-Thesis students must take at least 12 credits of CSCI 500-level coursework, excluding Independent Study credits. The following four core courses are required of all students. Students may choose elective courses from any CSCI graduate course offered by the Department. In addition, up to six credits of elective courses may be taken outside of CSCI. Lastly, a maximum of six Independent Study course units can be used to fulfill degree requirements.

| | | |
|---|---|---|
| CSCI406 | ALGORITHMS (offered every semester) | 3.0 |
| CSCI442 | OPERATING SYSTEMS (offered every semester) | 3.0 |
| CSCI561 | THEORY OF COMPUTATION (offered every fall) | 3.0 |
| CSCI564 | ADVANCED COMPUTER ARCHITECTURE (offered every spring) | 3.0 |

### MS Project Track

Students are required to take six credits of CSCI700 to fulfill the MS project requirement. (It is recommended that the six credits consist of two consecutive semesters of three credits each.) At most six credits of CSCI700 will be counted toward the Masters non-thesis degree. Deliverables include a report and a presentation to a committee of two CS faculty including the Advisor. Deliverables must be successfully completed in the last semester in which the student registers for CSCI700. A student must receive two "pass" votes (i.e., a unanimous vote) to satisfy the project option.

### MS Thesis Defense

At the conclusion of the MS (Thesis Option), the student will be required to make a formal presentation and defense of her/his thesis research. A student must “pass” this defense to earn an MS degree.

### CS Minor

A CS Minor at the Master's level requires a minimum of 9 semester hours of CSCI course work, of which, at leaset 6 semester hours of course work must be at the 500-level or above excluding independent studies and graduate seminars. Pursuant to Graduate School rules all minors must be approved by the student's advisor, home department head, and a faculty representative of the minor area of study. A minor may not be taken in the student's major area of study.

## Doctor of Philosophy - Computer Science

The PhD degree in Computer Science requires 72 credit hours of course work and research credits. Required course work provides a strong background in computer science. A course of study leading to the PhD degree can be designed either for the student who has completed the master's degree or for the student who has completed the bachelor's degree. The following five courses are required of all students. Students who have taken equivalent courses at another institution may satisfy these requirements by transfer.

| | | |
|---|---|---|
| CSCI406 | ALGORITHMS (offered every semester) | 3.0 |
| CSCI442 | OPERATING SYSTEMS (offered every semester) | 3.0 |
| CSCI561 | THEORY OF COMPUTATION (offered every fall) | 3.0 |
| CSCI564 | ADVANCED COMPUTER ARCHITECTURE (offered every spring) | 3.0 |
| SYGN502 | INTRODUCTION TO RESEARCH ETHICS | 1.0 |

### PhD Qualifying Examination

Students desiring to take the PhD Qualifying Exam must have:

- (if required by your advisor) taken SYGN 501 The Art of Science (previously or concurrently),
- Complete (previously or concurrently) at least four CSCI 500-level courses at Mines (only one CSCI599 is allowed), and
- maintained a GPA of 3.5 or higher in all CSCI 500-level courses taken.

The PhD Qualifying Exam must be taken no later than the fourth semester of study. Exception must be formally requested via email to the Qualifying Exam Committee Chair and approved by the Graduate Committee. The PhD Qualifying Exam is offered once a semester. Each PhD Qualifying Exam comprises of two research areas, chosen by the student. The exam consists of the following steps:

Step 1. A student indicates intention to take the CS PhD Qualifying Exam by choosing two research interest areas.

- The primary test area should be the same as the research area of the student's (potential) advisor. This exam will be more open-ended research than the second test area. A formal written report and a formal presentation meeting are required for this exam. The outcome of this exam can be part of the student's dissertation research. In fact, the student is strongly encouraged to create results that can lead to a publication. It is acceptable and encouraged if the advisor is involved to provide suggestions. The student is required to clearly document in the written report how the advisor was involved in the exam.

- The second test area should be from another research area of interest to the student that is (1) supported by faculty within the CS department and (2) different from the student's primary advisor's research area. It is highly recommended that the student choose their secondary test area with an instructor the student has had in one or more courses. This exam will likely be less substantial than the primary exam, e.g., instructions will be more concrete. The purpose of having a second test area is to ensure students can demonstrate both the breadth of knowledge and the capability in doing independent research. Thus, no faculty member is allowed to assist the student in this second exam except for answering clarification questions.

Students must inform the CS Graduate Committee Chair of their intention to take the exam no later than the first class day of the semester.

Step 2. The Graduate Committee Chair creates an exam committee of (at least) four appropriate faculty. The exam committee assigns the student specific tasks with corresponding deliverables for both research areas chosen. The tasks will be some combination from the following list:

- design and evaluate new algorithms or systems for an important research problem, and write a report that summarizes the design and the evaluation results;
- read a set of technical papers, write a summary of the papers read, make a presentation, and answer questions (presentations will be limited to 30-minutes with a hard stop not including Q&A);
- complete a hands-on activity (e.g., develop research software) and write a report that explains the difficulties with the activity and what was learned;
- complete a set of take-home problems;
- write a literature survey (i.e., track down references, separate relevant from irrelevant papers); and

Step 3. The student must complete all deliverables no later than the Monday of Dead Week (11:59pm). Failure to meet the deadline is considered a failed attempt. The submitted report on the deadline is considered to be final, i.e., no update is allowed after the due date/time. Before the oral presentation, the student is not allowed to practice the exam presentation with his/her advisor or research group to get feedback. The student will access exam problems, and submit deliverables through a specified system such as Canvas course/module. Additionally, the specified system will be used to deliver feedback from the committee to the student outlining strengths, weaknesses, recommendations and exam results.

Step 4. Each member of the exam committee makes a recommendation on the deliverables from the following list: strongly support, support, and do not support.To pass the PhD Qualifying Exam, the student must have at least two "strongly supports" and no more than one "do not support". If a student receives two or more "do not support" votes by the committee members, the student fails the exam. All other cases other than Pass or Fail are considered as Conditional Pass.

Conditional Pass Requirements

If a student receives a Conditional Pass, the student is required to take (an) additional test(s). The exam committee will explicitly specify the deadline for the student to take the additional test in the feedback comments to the student. The deadline will likely be at the beginning weeks of the following semester. The additional test(s) may be the whole or part(s) of the original qualifying exam or may be an additional task, as determined by the exam committee. If the student passes the assigned additional test, the Conditional Pass will be converted into a Pass; otherwise, the outcome of the qualifying exam will be a Fail.

The student is informed of the qualifying exam decision (Pass, Fail, or Conditional Pass) no later than the Monday after finals week. The student is informed of the outcome of a Conditional Pass test within two weeks after the test. A student can only fail the exam one time. If a second failure occurs, the student has unsatisfactory academic performance that results in an immediate, mandatory dismissal of the graduate student from the PhD program.

PhD Thesis Proposal: After passing the Qualifying Examination, the PhD student is allowed up to 18 months to prepare a written Thesis Proposal and present it formally to the student’s Thesis Committee and other interested faculty.

Admission to Candidacy: In addition to the Graduate School requirements, full-time PhD students must complete the following requirements within two calendar years of enrolling in the PhD program.

- Have a Thesis Committee appointment form on file in the Graduate Office:
- Have passed the PhD Qualifying Exam demonstrating adequate preparation for, and satisfactory ability to conduct doctoral research.

PhD Thesis Defense: At the conclusion of the student’s PhD program, the student will be required to make a formal presentation and defense of her/his thesis research. A student must “pass” this defense to earn a PhD degree.

## CS Minor

A CS Minor at the PhD level requires a minimum of 12 semester hours of CSCI course work, of which, 9 semester hours of course work must be at the 500-level or above excluding independent studies and graduate seminars. Pursuant to Graduate School rules all minors must be approved by the student's advisor, home department head, and a faculty representative of the minor area of study. A minor may not be taken in the student's major area of study.

# GRADUATE CERTIFICATE IN CYBERSECURITY FOR CYBER PHYSICAL SYSTEMS

**Program Requirements:**

**The program consists of four online graduate-level courses:**

| | | |
|---|---|---|
| CSCI560 | FUNDAMENTALS OF COMPUTER NETWORKS | 3.0 |
| CSCI574 | THEORY OF CRYPTOGRAPHY | 3.0 |
| CSCI585 | INFORMATION SECURITY PRIVACY | 3.0 |
| CSCI587 | CYBER PHYSICAL SYSTEMS SECURITY | 3.0 |
| Total Semester Hrs | | 12.0 |

# Post-Baccalaureate Professional Computer Science Certificate

**Program Requirements:**

**The program consists of five online undergraduate-level courses:**

| | | |
|---|---|---|
| CSCI261 | PROGRAMMING CONCEPTS | 3.0 |
| CSCI262 | DATA STRUCTURES | 3.0 |

| | | |
|---|---|---|
| CSCI303 | INTRODUCTION TO DATA SCIENCE | 3.0 |
| CSCI306 | SOFTWARE ENGINEERING | 3.0 |
| CSCI406 | ALGORITHMS | 3.0 |
| Total Semester Hrs | | 15.0 |

## Courses

**CSCI507. INTRODUCTION TO COMPUTER VISION. 3.0 Semester Hrs.**
Equivalent with CSCI437,CSCI512,EENG507,EENG512,
(I) Computer vision is the process of using computers to acquire images, transform images, and extract symbolic descriptions from images. This course provides an introduction to this field, covering topics in image formation, feature extraction, location estimation, and object recognition. Design ability and hands-on projects will be emphasized, using popular software tools. The course will be of interest both to those who want to learn more about the subject and to those who just want to use computer imaging techniques. Prerequisites: Undergraduate level knowledge of linear algebra, statistics, and a programming language. 3 hours lecture; 3 semester hours.

**CSCI508. ADVANCED TOPICS IN PERCEPTION AND COMPUTER VISION. 3.0 Semester Hrs.**
Equivalent with EENG508,
(II) This course covers advanced topics in perception and computer vision, emphasizing research advances in the field. The course focuses on structure and motion estimation, general object detection and recognition, and tracking. Projects will be emphasized, using popular software tools. Prerequisites: EENG507 or CSCI507. 3 hours lecture; 3 semester hours.

**CSCI522. INTRODUCTION TO USABILITY RESEARCH. 3.0 Semester Hrs.**
(I) An introduction to the field of Human-Computer Interaction (HCI). Students will review current literature from prominent researchers in HCI and will discuss how the researchers' results may be applied to the students' own software design efforts. Topics include usability testing, ubiquitous computing user experience design, cognitive walkthrough and talk-aloud testing methodologies. Students will work in small teams to develop and evaluate an innovative product or to conduct an extensive usability analysis of an existing product. Project results will be reported in a paper formatted for submission to an appropriate conference (UbiComp, SIGCSE, CHI, etc.). Prerequisite: CSCI 261 or equivalent. 3 hours lecture, 3 semester hours.

**CSCI532. ROBOT ETHICS. 3.0 Semester Hrs.**
(II) This course explores ethical issues arising in robotics and human-robot interaction through philosophical analysis, scientific experimentation, and algorithm design. Topics include case studies in lethal autonomous weapon systems, autonomous cars, and social robots, as well as higher-level concerns including economics, law, policy, and discrimination. Graduate enrollees will additionally participate in and report on the results of empirical and computational robot ethics research, with the goal of developing publishable works. Prerequisite: Graduate student standing.

**CSCI534. ROBOT PLANNING AND MANIPULATION. 3.0 Semester Hrs.**
An introduction to planning in the context of robotics covering symbolic and motion planning approaches. Symbolic computation, symbolic domains, and efficient algorithms for symbolic planning; Robot kinematics, configuration spaces, and algorithms for motion planning. Applications of planning will focus on manipulation problems using robot arms. Prerequisite: CSCI404 or graduate student standing.

**CSCI536. HUMAN-ROBOT INTERACTION. 3.0 Semester Hrs.**
Human-Robot Interaction is an interdisciplinary field at the intersection of Computer Science, Robotics, Psychology, and Human Factors, that seeks to answer a broad set of questions about robots designed to interact with humans (e.g., assistive robots, educational robots, and service robots), such as: (1) How does human interaction with robots differ from interaction with other people? (2) How does the appearance and behavior of a robot change how humans perceive, trust, and interact with that robot? And (3) How can we design and program robots that are natural, trustworthy, and effective? Accordingly, In this course, students will learn (1) how to design interactive robots, (2) the algorithmic foundations of interactive robots; and (3) how to evaluate interactive robots. To achieve these learning objectives, students will read and present key papers from the HRI literature, complete an individual final project tailored to their unique interests and skillsets, and complete a group project in which they will design, pilot, and evaluate novel HRI experiments, with in-class time expected to be split between lecture by the instructor, presentations by students, and either collaborative active learning activities or discussions with researchers in the field. Prerequisite: Data Structures, Probability and Statistics or equivalent.

**CSCI542. SIMULATION. 3.0 Semester Hrs.**
(I) Advanced study of computational and mathematical techniques for modeling, simulating, and analyzing the performance of various systems. Simulation permits the evaluation of performance prior to the implementation of a system; it permits the comparison of various operational alternatives without perturbing the real system. Topics to be covered include simulation techniques, random number generation, Monte Carlo simulations, discrete and continuous stochastic models, and point/interval estimation. Offered every other year. Prerequisite: CSCI 262 (or equivalent) and MATH 323 (or MATH 530 or equivalent). 3 hours lecture; 3 semester hours.

**CSCI544. ADVANCED COMPUTER GRAPHICS. 3.0 Semester Hrs.**
Equivalent with MATH544,
This is an advanced computer graphics course in which students will learn a variety of mathematical and algorithmic techniques that can be used to solve fundamental problems in computer graphics. Topics include global illumination, GPU programming, geometry acquisition and processing, point based graphics and non-photorealistic rendering. Students will learn about modern rendering and geometric modeling techniques by reading and discussing research papers and implementing one or more of the algorithms described in the literature.

**CSCI546. WEB PROGRAMMING II. 3.0 Semester Hrs.**
(I) This course covers methods for creating effective and dynamic web pages, and using those sites as part of a research agenda related to Humanitarian Engineering. Students will review current literature from the International Symposium on Technology and Society (ISTAS), American Society for Engineering Education (ASEE), and other sources to develop a research agenda for the semester. Following a brief survey of web programming languages, including HTML, CSS, JavaScript and Flash, students will design and implement a website to meet their research agenda. The final product will be a research paper which documents the students' efforts and research results. Prerequisite: CSCI 262. 3 hours lecture, 3 semester hours.

**CSCI547. SCIENTIFIC VISUALIZATION. 3.0 Semester Hrs.**
Equivalent with MATH547,
Scientific visualization uses computer graphics to create visual images which aid in understanding of complex, often massive numerical representation of scientific concepts or results. The main focus of this course is on techniques applicable to spatial data such as scalar, vector and tensor fields. Topics include volume rendering, texture based methods for vector and tensor field visualization, and scalar and vector field topology. Students will learn about modern visualization techniques by reading and discussing research papers and implementing one of the algorithms described in the literature.

**CSCI555. GAME THEORY AND NETWORKS. 3.0 Semester Hrs.**
Equivalent with CSCI455,
(II) An introduction to fundamental concepts of game theory with a focus on the applications in networks. Game theory is the study that analyzes the strategic interactions among autonomous decision-makers. Originated from economics. Influenced many areas in Computer Science, including artificial intelligence, e-commerce, theory, and security and privacy. Provides tools and knowledge for modeling and analyzing real-world problems. Prerequisites: CSCI406 Algorithms. 3 hours lecture; 3 semester hours.

**CSCI560. FUNDAMENTALS OF COMPUTER NETWORKS. 3.0 Semester Hrs.**
(II) This fully online course provides an introduction to fundamental concepts in the design and implementation of computer communication networks, their protocols, and applications. Topics include overview of network architectures, applications, network programming interfaces (e.g., sockets), transport, congestion, routing, and data link protocols, addressing, local area networks, wireless networks, and network security. Examples are drawn primarily from the Internet (e.g., TCP, UDP, and IP) protocol suite. Prerequisite: CSCI442. 3 hours lecture; 3 semester hours.

**CSCI561. THEORY OF COMPUTATION. 3.0 Semester Hrs.**
(I) An introduction to abstract models of computation and computability theory; including finite automata (finite state machines), pushdown automata, and Turing machines. Language models, including formal languages, regular expressions, and grammars. Decidability and undecidability of computational problems. 3 hours lecture; 3 semester hours. Prerequisite: CSCI406.

**CSCI562. APPLIED ALGORITHMS AND DATA STRUCTURES. 3.0 Semester Hrs.**
(II) Industry competitiveness in certain areas is often based on the use of better algorithms and data structures. The objective of this class is to survey some interesting application areas and to understand the core algorithms and data structures that support these applications. Application areas could change with each offering of the class, but would include some of the following: VLSI design automation, computational biology, mobile computing, computer security, data compression, web search engines, geographical information systems. Prerequisite: MATH/CSCI406. 3 hours lecture; 3 semester hours.

**CSCI563. PARALLEL COMPUTING FOR SCIENTISTS AND ENGINEERS. 3.0 Semester Hrs.**
(I) Students are taught how to use parallel computing to solve complex scientific problems. They learn how to develop parallel programs, how to analyze their performance, and how to optimize program performance. The course covers the classification of parallel computers, shared memory versus distributed memory machines, software issues, and hardware issues in parallel computing. Students write programs for state of the art high performance supercomputers, which are accessed over the network. Prerequisite: Programming experience in C. 3 hours lecture; 3 semester hours.

**CSCI564. ADVANCED COMPUTER ARCHITECTURE. 3.0 Semester Hrs.**
The objective of this class is to gain a detailed understanding about the options available to a computer architect when designing a computer system along with quantitative justifications for the options. All aspects of modern computer architectures including instruction sets, processor design, memory system design, storage system design, multiprocessors, and software approaches will be discussed. Prerequisite: CSCI341. 3 hours lecture; 3 semester hours.

**CSCI565. DISTRIBUTED COMPUTING SYSTEMS. 3.0 Semester Hrs.**
(II) This course discusses concepts, techniques, and issues in developing distributed systems in large scale networked environment. Topics include theory and systems level issues in the design and implementation of distributed systems. Prerequisites: CSCI 442 or equivalent. 3 hours of lecture; 3 semester hours.

**CSCI568. DATA MINING. 3.0 Semester Hrs.**
(II) This course is an introductory course in data mining. It covers fundamentals of data mining theories and techniques. We will discuss association rule mining and its applications, overview of classification and clustering, data preprocessing, and several applicationspecific data mining tasks. We will also discuss practical data mining using a data mining software. Project assignments include implementation of existing data mining algorithms, data mining with or without data mining software, and study of data mining related research issues. Prerequisite: CSCI262. 3 hours lecture; 3 semester hours.

**CSCI571. ARTIFICIAL INTELLIGENCE. 3.0 Semester Hrs.**
(I) Artificial Intelligence (AI) is the subfield of computer science that studies how to automate tasks for which people currently exhibit superior performance over computers. Historically, AI has studied problems such as machine learning, language understanding, game playing, planning, robotics, and machine vision. AI techniques include those for uncertainty management, automated theorem proving, heuristic search, neural networks, and simulation of expert performance in specialized domains like medical diagnosis. This course provides an overview of the field of Artificial Intelligence. Particular attention will be paid to learning the LISP language for AI programming. Prerequisite: CSCI262. 3 hours lecture; 3 semester hours.

**CSCI572. COMPUTER NETWORKS II. 3.0 Semester Hrs.**
This course explores how computer networking is evolving to support new environments, and challenges in building networked systems that are simultaneously highly robust, efficient, flexible, and secure. Detailed topics include wireless and mobile networks, multimedia networking, and network security. In addition, recent research and developments are also studied, which include mobile sensing, Internet of Things (IoT), social computing and networks, mobile ad-hoc networks, wireless sensor networks, software defined networking, and future Internet architecture. Prerequisite: CSCI262 or equivalent or instructor consent.

**CSCI573. HUMAN-CENTERED ROBOTICS. 3.0 Semester Hrs.**

Equivalent with CSCI473,

(II) Human-centered robotics is an interdisciplinary area that bridges research and application of methodology from robotics, machine vision, machine learning, human-computer interaction, human factors, and cognitive science. Students will learn about fundamental research in human-centered robotics, as well as develop computational models for robotic perception, internal representation, robotic learning, human-robot interaction, and robot cognition for decision making. Students in CSCI 473 will be able to model and analyze human behaviors geared toward human-robot interaction applications. They will also be able to implement a working system using algorithms learnt to solve a given problem in human-centered robotics application. Students in CSCI 573 will get a more in-depth study into the theory of the algorithms. They will be able to compare the different algorithms to select the most appropriate one that can solve a specific problem. Prerequisites: CSCI262 and MATH201. 3 hours lecture; 3 semester hours.

**CSCI574. THEORY OF CRYPTOGRAPHY. 3.0 Semester Hrs.**

Equivalent with MATH574,

(I) Students will draw upon current research results to design, implement and analyze their own computer security or other related cryptography projects. The requisite mathematical background, including relevant aspects of number theory and mathematical statistics, will be covered in lecture. Students will be expected to review current literature from prominent researchers in cryptography and to present their findings to the class. Particular focus will be given to the application of various techniques to real-life situations. The course will also cover the following aspects of cryptography: symmetric and asymmetric encryption, computational number theory, quantum encryption, RSA and discrete log systems, SHA, steganography, chaotic and pseudo-random sequences, message authentication, digital signatures, key distribution and key management, and block ciphers. Prerequisite: CSCI262. 3 hours lecture, 3 semester hours.

**CSCI575. MACHINE LEARNING. 3.0 Semester Hrs.**

(I) The goal of machine learning research is to build computer systems that learn from experience and that adapt to their environments. Machine learning systems do not have to be programmed by humans to solve a problem; instead, they essentially program themselves based on examples of how they should behave, or based on trial and error experience trying to solve the problem. This course will focus on the methods that have proven valuable and successful in practical applications. The course will also contrast the various methods, with the aim of explaining the situations in which each is most appropriate. Prerequisite: CSCI262, MATH201, MATH332.

**CSCI576. WIRELESS SENSOR SYSTEMS. 3.0 Semester Hrs.**

With the advances in computational, communication, and sensing capabilities, large scale sensor-based distributed environments are becoming a reality. Sensor enriched communication and information infrastructures have the potential to revolutionize almost every aspect of human life benefitting application domains such as transportation, medicine, surveillance, security, defense, science and engineering. Such a distributed infrastructure must integrate networking, embedded systems, distributed computing and data management technologies to ensure seamless access to data dispersed across a hierarchy of storage, communication, and processing units, from sensor devices where data originates to large databases where the data generated is stored and/or analyzed. Prerequisite: CSCI406, CSCI446, CSCI471. 3 hours lecture; 3 semester hours.

**CSCI578. BIOINFORMATICS. 3.0 Semester Hrs.**

Bioinformatics is a blend of multiple areas of study including biology, data science, mathematics and computer science. The field focuses on extracting new information from massive quantities of biological data and requires that scientists know the tools and methods for capturing, processing and analyzing large data sets. Bioinformatics scientists are tasked with performing high-throughput, next-generation sequencing. They analyze DNA sequence alignment to find mutations and anomalies and understand the impact on cellular processes. The bioinformatician uses software to analyze protein structure and its impact on cell function. Learning how to design experiments and perform advanced statistical analysis is essential for anyone interested in this field, which is main goal of this course.

**CSCI580. ADVANCED HIGH PERFORMANCE COMPUTING. 3.0 Semester Hrs.**

This course provides students with knowledge of the fundamental concepts of high performance computing as well as hands-on experience with the core technology in the field. The objective of this class is to understand how to achieve high performance on a wide range of computational platforms. Topics will include sequential computers including memory hierarchies, shared memory computers and multicore, distributed memory computers, graphical processing units (GPUs), cloud and grid computing, threads, OpenMP, message passing (MPI), CUDA (for GPUs), parallel file systems, and scientific applications. 3 hours lecture; 3 semester hours.

**CSCI581. QUANTUM PROGRAMMING. 3.0 Semester Hrs.**

This course serves as an introduction to programming quantum computers. Students will receive an in depth education in quantum algorithms and their design, and then break into teams to learn the API of a commercially available quantum computing system. They will use this system to write and test simple quantum algorithms, and debug their code to improve its performance against noise and other error sources. Prerequisite: PHGN519.

**CSCI585. INFORMATION SECURITY PRIVACY. 3.0 Semester Hrs.**

(II) This course provides an introduction to the principles and best practices in information security and privacy. Lectures will include basic concepts of information security and privacy, fundamental security design principles, major topics in security and privacy, essential knowledge and skills, risk assessment and mitigation, policy development, and so on. In the classroom, students will also present and discuss a list of recent or classic research papers corresponding to the major topics in security and privacy. Outside of the classroom, students will work on homework assignments, security lab exercises, quizzes, research paper summaries, and a course project. Prerequisite: CSCI262, CSCI341. 3 hours lecture; 3 semester hours.

**CSCI587. CYBER PHYSICAL SYSTEMS SECURITY. 3.0 Semester Hrs.**

(II) This course aims to build a solid foundation for students to identify, analyze, and evaluate real-world security and privacy problems in Cyber Physical Systems, as well as to design and develop secure and usable solutions for addressing these problems. It focuses on the important security and privacy research topics in representative Cyber Physical Systems such as wireless sensor networks, smart grids, autonomous automotive systems, and robotic systems. It also includes the discussion of the protection of the nation?s critical infrastructures such as Food, Health, Water, Energy, Finance, Communication, Manufacturing, Government, and Transportation. The format of the course includes introductory discussions, research paper reading, summaries, and discussions, as well as research projects. 3 hours lecture; 3 semester hours.

**CSCI598. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**CSCI599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**CSCI691. GRADUATE SEMINAR. 1.0 Semester Hr.**
Presentation of latest research results by guest lecturers, staff, and advanced students. Prerequisite: none. 1 hour seminar; 1 semester hour. Repeatable for credit to a maximum of 12 hours.

**CSCI692. GRADUATE SEMINAR. 1.0 Semester Hr.**
Equivalent with MATH692,
Presentation of latest research results by guest lecturers, staff, and advanced students. Prerequisite: none. 1 hour seminar; 1 semester hour. Repeatable for credit to a maximum of 12 hours.

**CSCI693. WAVE PHENOMENA SEMINAR. 1.0 Semester Hr.**
Students will probe a range of current methodologies and issues in seismic data processing, with emphasis on underlying assumptions, implications of these assumptions, and implications that would follow from use of alternative assumptions. Such analysis should provide seed topics for ongoing and subsequent research. Topic areas include: Statistics estimation and compensation, deconvolution, multiple suppression, suppression of other noises, wavelet estimation, imaging and inversion, extraction of stratigraphic and lithologic information, and correlation of surface and borehole seismic data with well log data. Prerequisite: none. 1 hour seminar; 1 semester hour.

**CSCI698. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**CSCI699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**CSCI700. MASTERS PROJECT CREDITS. 1-6 Semester Hr.**
(I, II, S) Project credit hours required for completion of the non-thesis Master of Science degree in Computer Science (Project Option). Project under the direct supervision of a faculty advisor. Credit is not transferable to any 400, 500, or 600 level courses. Repeatable for credit.

**CSCI707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) GRADUATE THESIS/DISSERTATION RESEARCH CREDIT Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

## Professor and Department Head

Tracy Camp

## Professors

Qi Han

Dinesh Mehta

## Associate professors

William Hoff

Hua Wang

Bo Wu

Dejun Yang

Chuan Yue

## Assistant professors

Mehmet Belviranli

Neil Dantam

Jedidiah McClurg

Thomas Williams

Hao Zhang

## Teaching Professors

Vibhuti Dave

Christopher Painter-Wakefield

## Teaching Associate Professors

Wendy Fisher, Assistant Department Head

Jeffrey Paone

## Professor of Practice

Mark Baldwin

## Emeritus Teaching Professor

Cyndi Rader

# Economics and Business

## Degrees Offered

- Master of Science (Mineral and Energy Economics)
- Doctor of Philosophy (Mineral and Energy Economics)
- Master of Science (Engineering and Technology Management)
- Graduate Certificate in Resource Commodity Analytics (RCA)
- Graduate Certificate in Business Analytics
- Graduate Certificate in Entrepreneurship
- Graduate Certificate in Product Management

## Mineral and Energy Economics Program Description

In an increasingly global and technical world, government and industry leaders in the mineral and energy areas require a strong foundation in economic and business skills. The Division offers such skills in unique programs leading to M.S. and Ph.D. degrees in Mineral and Energy Economics. Course work and research emphasizes the use of models to aid in decision making. Beyond the core courses students in the Mineral and Energy Economics Program may select, in consultation with their advisor from a set of electives that fit their specialized needs and educational goals.  This may include advanced courses in Applied Economics, Finance, and Operations Research.

## Engineering and Technology Management Program Description

The Division also offers an M.S. degree in Engineering and Technology Management (ETM). The ETM degree program is designed to integrate the technical elements of engineering practice with the managerial perspective of modern engineering and technology management. A major focus is on the business and management principles related to this integration. The ETM Program provides the analytical tools and managerial perspective needed to effectively function in a highly competitive and technologically complex business economy.

Students in the ETM Program may select elective courses from two areas of focus:  Engineering Management and Optimization or Technology Management and Innovation. The Optimization courses focus on developing knowledge of advanced operations research, optimization, and decision making techniques applicable to a wide array of business and engineering problems.  The Engineering Management courses emphasize valuable techniques for managing large engineering and technical projects effectively and efficiently.  The Strategy and Innovation courses teach the correct match between organizational strategies and structures to maximize the competitive power of technology with a particular emphasis on management issues associated with the modern business enterprise.

## Combined Degree Program Option

Mines undergraduate students have the opportunity to begin work on a M.S. degree in Mineral and Energy Economics or Engineering & Technology Management while completing their Bachelor's degree at Mines. The Mineral and Energy Economics Combined Degree Program provides the vehicle for students to use undergraduate coursework as part of their Graduate Degree curriculum. For more information please contact the EB Office or visit econbus.mines.edu.

## Graduate Certificate in Resource Commodity Analytics

The Mines graduate certificate in Resource Commodity Analytics (RCA) is a four-course program that provides training in advanced quantitative and financial analysis applied to energy and mineral industries. The RCA certificate program takes the most quantitative aspects of our world-renowned graduate programs in Mineral and Energy Economics, and Engineering and Technology Management, and distills them into an accelerated certificate. This program is designed for professionals and recent graduates who want to acquire new skills for career advancement or get a head start on a graduate degree. Courses in the program focus on natural resource markets & regulation, data analysis & forecasting, and financial valuation. The course of study is flexible enough to be completed in one intensive semester or over four semesters depending on the student's needs and interests.

In an increasingly global and technical world, government and industry leaders in the mineral and energy areas require a strong foundation in economic and business skills. The Division offers such skills in unique programs leading to MS and PhD degrees in Mineral and Energy Economics. Course work and research emphasizes the use of models to aid in decision making.  Beyond the core courses students in the Mineral and Energy Economics Program select, in consultation with their advisor, from a set of electives that fit their specialized needs and educational goals. This may include advanced courses in Applied Economics, Finance, and Operations Research.

## Mineral and Energy Economics Program Requirements

**MS Degree** Students choose from either the thesis or non-thesis option in the Master of Science (MS) Program and are required to complete a minimum total of 36 credits (a typical course has 3 credits). Initial admission is only to the non-thesis program. Admission to the thesis option requires subsequent application after at least one full-time equivalent semester in the program.

| **Non-thesis option** | |
|---|---|
| Core courses | 15.0 |
| Approved electives* | 21.0 |
| Total Semester Hrs | 36.0 |

| **Thesis option** | |
|---|---|
| Core courses | 15.0 |
| Research credits | 12.0 |
| Approved electives* | 9.0 |
| Total Semester Hrs | 36.0 |

* Non-thesis MS students may apply six elective credits toward a nine hour minor in another department.  See below for details.

**Further Degree Requirements**

All thesis and non-thesis students in the Mineral and Energy Economics Program are required to attend the Distinguished Lecture Series sponsored by the Payne Institute for Earth Resources and the Division of Economics and Business.  This series facilitates active involvement in the Mineral and Energy Economics Program by top researchers and influential leaders in the policy arena.  The Program Director will outline attendance requirements at the beginning of each fall semester.

**PhD Degree** Doctoral students develop a customized curriculum to fit their needs. The degree requires a minimum of 72 graduate credit hours that includes course work and a thesis.

| Course work (requires advisor and committee approval) | |
|---|---|
| First year Core courses | 15.0 |
| Extended Core | 3.0 |
| Approved electives | 18.0 |
| Total Semester Hrs | 36.0 |

**Research credits**

| | |
|---|---|
| Research credits | 36.0 |

The student's faculty advisor and the doctoral thesis committee must approve the student's program of study and the topic for the thesis.

## Qualifying Examination Process

Upon completion of the first-year core course work, PhD students must pass a first set of qualifying written examinations (collectively Qualifier 1). A student will receive one of four possible grades on the Micro Economics and Quantitative Methods examinations: High Pass, Pass, Marginal Fail, or Fail. A student receiving a marginal fail on one, or both of the examinations will have the opportunity to retake the relevant examination(s) within a year of the initial attempt.  Students receiving a marginal fail should consult their adviser as to whether to retake exams during the winter or summer breaks. A student receiving a Fail, or consecutive Marginal Fails, will be dismissed from the program. Consistent with university policy, the faculty will grade and inform students of qualification examination results within two weeks of the examinations.

Upon completion of the extended core (typically in the second year), PhD students must pass a second qualifying written examination (Qualifier II). A student will receive one of four possible grades on Qualifier II: High Pass, Pass, Marginal Fail, or Fail. A student receiving a Marginal Fail on Qualifier II will have the opportunity to retake the exam, or relevant portions of the exam as determined by the examination committee, within a year of the initial attempt. Students receiving a marginal fail should consult their advisor as to whether to retake exams during the winter or summer breaks. A student receiving a Fail or consecutive Marginal Fails, on Qualifier II will be dismissed from the program. Consistent with university policy, the faculty will grade and inform students of qualification examination results within two weeks of the examinations.

Following a successful thesis-proposal defense and prior to the final thesis defense, a student is required to present a completed research paper (or dissertation chapter) in a research seminar at Mines. The research presentation must be considered satisfactory by at least three Mines faculty members in attendance.

## Minor from Another Department

Non-thesis MS students may apply six elective credits towards a nine hour minor in another department. A minor is ideal for those students who want to enhance or gain knowledge in another field while gaining the economic and business skills to help them move up the career ladder. For example, a petroleum, chemical, or mining engineer might want to learn more about environmental engineering, a geophysicist or geologist might want to learn the latest techniques in their profession, or an economic policy analyst might want to learn about political risk. Students should check with the minor department for the opportunities and requirements.

**Transfer Credits**

The student must have achieved a grade of B or better in all graduate transfer courses and the transfer credit must be approved by the student's advisor and the Division Director. The total number of transfer credits allowed in the Mineral and Energy Economics program will follow Colorado School of Mines Graduate School rules.

**Unsatisfactory Progress**

In addition to the institutional guidelines for unsatisfactory progress as described elsewhere in this bulletin. Unsatisfactory progress will be assigned to any full-time student who does not pass the first year core courses on time. EBGN509, EBGN510 and EBGN521 in the first fall semester of study; and  EBGN590 in the first spring semester of study. Unsatisfactory progress will also be assigned to any students who do not complete requirements as specified in their admission letter. Part-time students develop an approved course plan with their advisor.

PhD Students are expected to take the first set of qualification examinations (Qualifier I) in the first summer following eligibility. Unsatisfactory progress may be assigned to any student who does not meet this expectation.  Consistent with university policy, consideration will be given to students who have documented illness or other qualifying personal event that prevents them from taking Qualifier I.  A marginal fail on a qualification examination does not trigger the assignment of unsatisfactory progress.  Unsatisfactory progress will, however be assigned to a student who fails to retake a marginally failed examination in the next available summer offering.

## Mines' Combined Undergraduate/Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any 400+ level courses that count towards the undergraduate degree requirements as "Elective Coursework" or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a "B-" or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

## Colorado Mesa University Combined Undergraduate/Graduate Degree Program

Please see Mines Registrar Transfer Agreements web page for detailed information.

The Colorado School of Mines shares a Memorandum of Understanding (MoU) with Colorado Mesa University. This MoU grants students with the opportunity to apply up to six undergraduate-coursework credits earned from Colorado Mesa University towards their Mines graduate-degree requirements. These credit-hours must be from an approved list of courses. Students are advised to contact the Graduate Program Manager [or equivalent] of the Mineral and Energy Economics program regarding the specific terms and eligible courses for which this agreement applies.

| **Non-thesis option** | |
|---|---|
| Core courses | 15.0 |
| Approved electives | 12.0 |
| CMU 400-level electives | 9.0 |
| Total Semester Hrs | 36.0 |

## Dual Degree

The MS degree may be combined with a second degree from the IFP School (Paris, France) in Petroleum Economics and Management (see http://www.ifp.fr). This dual-degree program is geared to meet the needs of industry and government. Our unique program trains the next generation of technical, analytical and managerial professionals vital to the future of the petroleum and energy industries

These two world-class institutions offer a rigorous and challenging program in an international setting. The program gives a small elite group of students a solid economics foundation combined with quantitative business skills, the historical and institutional background, and the interpersonal and intercultural abilities to in the fast paced, global world of oil and gas.

Degrees: After studying in English for only 16 months (8 months at Mines and 8 months at IFP) the successful student of Petroleum Economics and Management (PEM) receives not 1 but 2 degrees:

- Masters of Science in Mineral and Energy Economics from Mines and
- Diplôme D'Ingénieur or Mastère Spécialisé from IFP

Important: Applications for admission to the joint degree program should be submitted for consideration by March 1st to begin the program the following fall semester in August. A limited number of students are selected for the program each year.

## Prerequisites for the Mineral and Energy Economics Programs

Students must have completed the following undergraduate prerequisite courses prior to beginning the program with a grade of B or better:

1. Principles of Microeconomics;
2. One semester of college-level Calculus;
3. Probability and Statistics

Students will only be allowed to enter in the spring semester if they have completed all three prerequisites courses previously, as well as undergraduate courses in mathematical economics and natural resource economics.

## Required Course Curriculum in Mineral and Energy Economics

All MS and PhD.students in Mineral and Energy Economics are required to take a set of core courses that provide basic tools for the more advanced and specialized courses in the program.

## 1. MS Curriculum

**a. Core Courses**

| | | |
|---|---|---|
| EBGN509 | MATHEMATICAL ECONOMICS | 3.0 |
| EBGN510 | NATURAL RESOURCE ECONOMICS | 3.0 |
| EBGN521 | MICROECONOMICS OF MINERAL AND ENERGY MARKETS | 3.0 |
| EBGN590 | ECONOMETRICS I | 3.0 |
| EBGN690 | ECONOMETRICS II * An alternative econometrics elective may be substituted for EBGN690 (for example, EBGN594 Time-series Econometrics) | 3.0 |
| Total Semester Hrs | | 15.0 |

**b. Approved Electives (21 credits for MS non-thesis option or 9 credits for MS thesis option)**

All EBGN graduate courses are approved electives. Other courses outside of Economics and Business can be counted with advisor and program director approval.

## 2. PhD Curriculum

**a. Common Core Courses**

| | | |
|---|---|---|
| EBGN509 | MATHEMATICAL ECONOMICS | 3.0 |
| EBGN510 | NATURAL RESOURCE ECONOMICS | 3.0 |
| EBGN521 | MICROECONOMICS OF MINERAL AND ENERGY MARKETS | 3.0 |
| EBGN590 | ECONOMETRICS I | 3.0 |
| EBGN690 | ECONOMETRICS II * An alternative econometrics elective may be substituted for EBGN690 (for example, EBGN594 Time-series Econometrics) | 3.0 |
| Total Semester Hrs | | 15.0 |

**b. Extended Core Courses**

| | | |
|---|---|---|
| EBGN611 | ADVANCED MICROECONOMICS | 3.0 |
| Total Semester Hrs | | 3.0 |

c. Approved Electives (18 credit hours)

The student, in consultation with their advisor, will choose six additional courses. A minimum of two courses must be Advanced Economics courses. The program of study can be customized to fit the individual student's educational goals, but must be approved by their advisor.

## Engineering and Technology Management (ETM) Master of Science Program Requirements

Students choose either the thesis or non-thesis option and complete a minimum of 30 credit hours. Initial admission is only to the non-thesis program. Admission to the thesis option requires subsequent application after admission to the ETM program.

| **Non-thesis option** | |
|---|---|
| Core courses | 15.0 |
| Elective courses | 15.0 |
| Total Semester Hrs | 30.0 |

| **Thesis option** | |
|---|---|
| Core courses | 15.0 |
| Research credits | 6.0 |

| | |
|---|---|
| Elective courses | 9.0 |
| Total Semester Hrs | 30.0 |

Students must receive approval from their advisor in order to apply non-EB Division courses towards their ETM degree. Thesis students are required to complete 6 credit hours of thesis credit and complete a Master's level thesis under the direct supervision of the student's thesis advisor.

## Further Degree Requirements

All thesis and non-thesis ETM MS students have four additional degree requirements:

1. the Executive-in-Residence seminar series;
2. the ETM Communications workshop;
3. the Leadership and Team Building workshop;
4. Economic Evaluation workshop.

All students are required to attend the ETM Program Executive-in-Residence seminar series during their first spring semester of study in the ETM Program. The Executive-in-Residence series features executives from industry who pass on insight and knowledge to graduate students preparing for positions in industry. This series facilitates active involvement in the ETM program by industry executives through teaching, student advising activities and more. Every spring semester the Executive-in-Residence will present a number of seminars on a variety of topics related to leadership and strategy in the engineering and technology sectors.

In addition, all students in their first fall semester of study in the ETM Program are required to attend a Communications workshop, a Leadership and Team Building workshop and an Economic Evaluation workshop.  The Communications workshop will provide students with a comprehensive approach to good quality communication skills, including presentation proficiency, organizational skills, professional writing skills, meeting management, as well as other professional communication abilities. This workshop is designed to better prepare students for the ETM learning experience and their professional careers.  The Leadership and Team Building workshop consists of non-competitive games, trust exercises and problem solving challenges and will introduce students to one another and provide opportunities to learn and practice leadership and team skills.  Finally, the Economic Evaluation workshop provides an overview engineering economics and the criteria used to evaluate investment decisions in technology-based industries.

## Mines' Combined Undergraduate/Graduate Degree Program

Students in an approved combined degree program who take ETM classes from the list below as undergraduate electives are able to double count six of these credits towards the MS degree in ETM.

Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any 400+ level courses that count towards the undergraduate degree requirements as "Elective Coursework" or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a "B-" or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

| | | |
|---|---|---|
| EBGN425 | BUSINESS ANALYTICS | 3.0 |
| EBGN525 | BUSINESS ANALYTICS | 3.0 |
| EBGN553 | PROJECT MANAGEMENT | 3.0 |
| EBGN560 | DECISION ANALYTICS | 3.0 |
| EBGN563 | MANAGEMENT OF TECHNOLOGY | 3.0 |
| MEGN485 | MANUFACTURING OPTIMIZATION WITH NETWORK MODELS | 3.0 |
| MEGN486 | LINEAR OPTIMIZATION | 3.0 |
| MEGN487 | NONLINEAR OPTIMIZATION | 3.0 |
| MEGN488 | INTEGER OPTIMIZATION | 3.0 |
| MEGN585 | NETWORK MODELS | 3.0 |
| MEGN586 | LINEAR OPTIMIZATION | 3.0 |
| MEGN587 | NONLINEAR OPTIMIZATION | 3.0 |
| MEGN588 | INTEGER OPTIMIZATION | 3.0 |
| PEGN438 | PETROLEUM DATA ANALYTICS | 3.0 |

Additional courses may be added subject to the approval of the ETM Program Director.

**Transfer Credits**

Students who enter the MS in Engineering and Technology Management program may transfer up to 6 graduate course credits into the degree program. The student must have achieved a grade of B or better in all graduate transfer courses and the transfer credit must be approved by the student's advisor and the Director of the ETM Program.

## Required Curriculum MS Degree Engineering and Technology Management

Thesis and non-thesis students are required to complete the following 15 hours of core courses which ideally should be taken at the first available opportunity:

**a. Core Courses**

| | | |
|---|---|---|
| EBGN525 | BUSINESS ANALYTICS | 3.0 |
| EBGN540 | ACCOUNTING AND FINANCE | 3.0 |
| EBGN553 | PROJECT MANAGEMENT | 3.0 |
| EBGN563 | MANAGEMENT OF TECHNOLOGY | 3.0 |
| EBGN585 | ENGINEERING AND TECHNOLOGY MANAGEMENT CAPSTONE (to be taken during the final semester of coursework) | 3.0 |
| Total Semester Hrs | | 15.0 |

**b. Elective courses (15 credits required for non-thesis option or 9 credits required for thesis option)**

| | | |
|---|---|---|
| **Engineering Management and Analytic Methods** | | |
| EBGN526 | STOCHASTIC MODELS IN MANAGEMENT SCIENCE | 3.0 |
| EBGN528 | INDUSTRIAL SYSTEMS SIMULATION | 3.0 |
| EBGN555 | LINEAR PROGRAMMING | 3.0 |
| EBGN559 | SUPPLY CHAIN MANAGEMENT | 3.0 |
| EBGN560 | DECISION ANALYTICS | 3.0 |
| EBGN571 | MARKETING ANALYTICS | 3.0 |

| **Technology Management and Innovation** | | |
|---|---|---|
| EBGN515 | ECONOMICS AND DECISION MAKING | 3.0 |
| EBGN566 | TECHNOLOGY ENTREPRENEURSHIP | 3.0 |
| EBGN567 | BUSINESS LAW AND ETHICS | 3.0 |
| EBGN572 | INTERNATIONAL BUSINESS STRATEGY | 3.0 |
| EBGN573 | ENTREPRENEURIAL FINANCE | 3.0 |
| EBGN576 | MANAGING AND MARKETING NEW PRODUCT DEVELOPMENTS | 3.0 |
| EBGN562 | STRATEGIC DECISION MAKING | 3.0 |
| EBGN577 | LEADING & MANAGING HIGH PERFORMING TEAMS | 3.0 |
| EBGN5XX | SPECIAL TOPICS IN ECONOMICS AND BUSINESS | 3.0 - 9.0 |

## Program Requirements

## Graduate Certificate in Resource Commodity Analytics

The graduate certificate requirements are to complete at least one course from the list of required courses, and nine additional credits either from the required courses list or the electives list. EBGN599 Independent study may satisfy no more than three credits of the certificate requirement. EBGN540 requires consent of instructor. Full-time students intending to complete the certificate in one semester must enter in the fall; part-time students can enter in the spring or fall.

Required courses (complete one of the following):

| | | |
|---|---|---|
| EBGN510 | NATURAL RESOURCE ECONOMICS | 3.0 |
| EBGN590 | ECONOMETRICS I | 3.0 |

Elective courses:

| | | |
|---|---|---|
| EBGN504 | ECONOMIC EVALUATION AND INVESTMENT DECISION METHODS | 3.0 |
| EBGN540 | ACCOUNTING AND FINANCE | 3.0 |
| EBGN560 | DECISION ANALYTICS | 3.0 |
| EBGN575 | ADVANCED MINING AND ENERGY ASSET VALUATION | 3.0 |
| EBGN594 | TIME-SERIES ECONOMETRICS | 3.0 |
| EBGN632 | PRIMARY FUELS | 3.0 |
| EBGN645 | COMPUTATIONAL ECONOMICS | 3.0 |
| EBGN599 | INDEPENDENT STUDY | 3.0 |

## Program Requirements

## Graduate Certificate in Business Analytics

The certificate requirements are to complete the following three courses:

| | | |
|---|---|---|
| EBGN525 | BUSINESS ANALYTICS | 3.0 |
| EBGN560 | DECISION ANALYTICS | 3.0 |
| EBGN571 | MARKETING ANALYTICS | 3.0 |

Course substitutions can be approved on a case-by-case basis by the certificate directors.  Completing the certificate will also position students to complete either the MS ETM degree or MS in Data Science degree as all the certificate courses can be applied to either degree.

## Program Requirements

## Graduate Certificate in Entrepreneurship

The certificate requirements are to complete three courses as follows:

| | | |
|---|---|---|
| EBGN573 | ENTREPRENEURIAL FINANCE | 3.0 |
| EBGN566 | TECHNOLOGY ENTREPRENEURSHIP | 3.0 |
| EBGN577 | LEADING & MANAGING HIGH PERFORMING TEAMS | 3.0 |

Course substitutions can be approved on a case-by-case basis by the certificate director.  Completing the certificate will also position students to complete the MS ETM degree.

## Program Requirements

## Graduate Certificate in Product Management

The certificate requirements are to complete the following three courses:

| | | |
|---|---|---|
| EBGN553 | PROJECT MANAGEMENT | 3.0 |
| EBGN563 | MANAGEMENT OF TECHNOLOGY | 3.0 |
| EBGN576 | MANAGING AND MARKETING NEW PRODUCT DEVELOPMENTS | 3.0 |

Course substitutions can be approved on a case-by-case basis by the certificate directors.  Completing the certificate will also position students to complete the MS ETM degree as all the certificate courses can be applied to the ETM degree.

## Courses

**EBGN504. ECONOMIC EVALUATION AND INVESTMENT DECISION METHODS. 3.0 Semester Hrs.**
Time value of money concepts of present worth, future worth, annual worth, rate of return and break-even analysis are applied to after-tax economic analysis of mineral, petroleum and general investments. Related topics emphasize proper handling of (1) inflation and escalation, (2) leverage (borrowed money), (3) risk adjustment of analysis using expected value concepts, and (4) mutually exclusive alternative analysis and service producing alternatives. Case study analysis of a mineral or petroleum investment situation is required. Students may not take EBGN504 for credit if they have completed EBGN321.

**EBGN509. MATHEMATICAL ECONOMICS. 3.0 Semester Hrs.**
This course reviews and re-enforces the mathematical and computer tools that are necessary to earn a graduate degree in Mineral Economics. It includes topics from differential and integral calculus; probability and statistics; algebra and matrix algebra; difference equations; and linear, mathematical and dynamic programming. It shows how these tools are applied in an economic and business context with applications taken from the mineral and energy industries. It requires both analytical as well as computer solutions. At the end of the course you will be able to appreciate and apply mathematics for better personal, economic and business decision making. Prerequisites: Principles of Microeconomics, and MATH111.

**EBGN510. NATURAL RESOURCE ECONOMICS. 3.0 Semester Hrs.**
The threat and theory of resource exhaustion; commodity analysis and the problem of mineral market instability; cartels and the nature of mineral pricing; the environment; government involvement; mineral policy issues; and international mineral trade. This course is designed for entering students in mineral economics. Prerequisite: Principles of Microeconomics.

**EBGN511. MICROECONOMICS. 3.0 Semester Hrs.**
(I, II, S) This is a graduate course dealing with applied microeconomic theory. The course concentrates on the behavior of individual segments of the economy, the theory of consumer behavior and demand, duality, welfare measures, policy instruments, preferences over time and states of nature, and the fundamentals of game theory. Prerequisites: MATH111, EBGN509. 3 hours lecture; 3 semester hours.

**EBGN512. MACROECONOMICS. 3.0 Semester Hrs.**
This course will provide an introduction to contemporary macroeconomic concepts and analysis. Macroeconomics is the study of the behavior of the economy as an aggregate. Topics include the equilibrium level of inflation, interest rates, unemployment and the growth in national income. The impact of government fiscal and monetary policy on these variables and the business cycle, with particular attention to the effects on the mineral industry. Prerequisites: Principles of Microeconomics, MATH111.

**EBGN515. ECONOMICS AND DECISION MAKING. 3.0 Semester Hrs.**
The application of microeconomic theory to business strategy. Understanding the horizontal, vertical, and product boundaries of the modern firm. A framework for analyzing the nature and extent of competition in a firm's dynamic business environment. Developing strategies for creating and sustaining competitive advantage.

**EBGN521. MICROECONOMICS OF MINERAL AND ENERGY MARKETS. 3.0 Semester Hrs.**
(I) This is a graduate course dealing with applied microeconomic theory. This course concentrates on the behavior of the minerals and energy segment of the economy, the theory of production and cost, the theory of consumer behavior and demand, derived demand, price and output level determination by firms, and the competitive structure of product and input markets. Prerequisites: MATH111, EBGN509. 3 hours lecture; 3 semester hours.

**EBGN523. MINERAL AND ENERGY POLICY. 3.0 Semester Hrs.**
(II) An analysis of current topics in the news in mineral and energy issues through the lens of economics. Since many of the topics involve government policy, the course provides instruction related to the economic foundations of mineral and energy policy analysis. 3 credit hours.

**EBGN525. BUSINESS ANALYTICS. 3.0 Semester Hrs.**
(I) This introductory course provides an analytic approach to problems that arise in business. Evaluating alternative courses of action in today's competitive business environment requires the extensive use of data based analytic methods. This course covers deterministic optimization models such as linear programming, non-linear programming, integer programming, and network modeling and an introduction to probability models and linear regression. Applications of the models are covered using spreadsheets. The intent of the course is to enhance analytic modeling abilities and to develop quantitative managerial and spreadsheet skills to support and improve decision making. The models cover applications in the areas of earth, energy, production, logistics, work force scheduling, marketing and finance. 3 hours lecture; 3 semester hours.

**EBGN526. STOCHASTIC MODELS IN MANAGEMENT SCIENCE. 3.0 Semester Hrs.**
(II) This course introduces the tools of stochastic modeling that are very useful in solving analytical problems in business. We cover methodologies that help to quantify the dynamic relationships of sequences of random events that evolve over time. Topics include static and dynamic Monte-Carlo simulation, discrete and continuous time Markov chains, probabilistic dynamic programming, Markov decision processes, queuing processes and networks, Brownian motion and stochastic control. Applications from a wide range of fields will be introduced including marketing, finance, production, logistics and distribution, energy and service systems. In addition to an intuitive understanding of analytical techniques to model stochastic processes, the course emphasizes how to use related software packages for managerial decision-making. 3 hours lecture; 3 semester hours.

**EBGN528. INDUSTRIAL SYSTEMS SIMULATION. 3.0 Semester Hrs.**
The course focuses on creating computerized models of real or proposed complex systems for performance evaluation. Simulation provides a cost effective way of pre-testing proposed systems and answering ?what-if? questions before incurring the expense of actual implementations. The course is instructed in the state-of-the-art computer lab (CTLM), where each student is equipped with a personal computer and interacts with the instructor during the lecture. Professional version of a widely used commercial software package, ?Arena?, is used to build models, analyze and interpret the results. Other business analysis and productivity tools that enhance the analysis capabilities of the simulation software are introduced to show how to search for optimal solutions within the simulation models. Both discrete-event and continuous simulation models are covered through extensive use of applications including call centers, various manufacturing operations, production/inventory systems, bulk-material handling and mining, port operations, high-way traffic systems and computer networks. Prerequisites: MATH111, MATH530.

**EBGN530. ECONOMICS OF INTERNATIONAL ENERGY MARKETS. 3.0 Semester Hrs.**
Application of models to understand markets for oil, gas, coal, electricity, and renewable energy resources. Models, modeling techniques, and issues included are supply and demand, market structure, transportation models, game theory, futures markets, environmental issues, energy policy, energy regulation, input/output models, energy conservation, and dynamic optimization. The emphasis in the course is on the development of appropriate models and their application to current issues in energy markets. Prerequisites: Principles of Microeconomics, MATH111, EBGN509, EBGN510, EBGN511.

**EBGN535. ECONOMICS OF METAL INDUSTRIES AND MARKETS. 3.0 Semester Hrs.**
(I, II, S) Metal supply from main product, byproduct, and secondary production. Metal demand and intensity of use analysis. Market organization and price formation. Public policy, comparative advantage, and international metal trade. Metals and economic development in the developing countries and former centrally planned economies. Environmental policy and mining and mineral processing. Students prepare and present a major research paper. Prerequisites: EBGN201, MATH111, EBGN509, and EBGN510. 3 hours lecture; 3 semester hours.

**EBGN536. MINERAL POLICIES AND INTERNATIONAL INVESTMENT. 3.0 Semester Hrs.**

Identification and evaluation of international mineral investment policies and company responses using economic, business and legal concepts. Assessment of policy issues in light of stakeholder interests and needs. Theoretical issues are introduced and then applied to case studies, policy drafting, and negotiation exercises to assure both conceptual and practical understanding of the issues. Special attention is given to the formation of national policies and corporate decision making concerning fiscal regimes, project financing, environmental protection, land use and local community concerns and the content of exploration and extraction agreements. Prerequisites: Principles of Microeconomics, MATH111, EBGN509, EBGN510, EBGN511.

**EBGN537. ECONOMICS OF WATER. 3.0 Semester Hrs.**

(II) This course seeks to develop the underlying economic logic of water use and how policy impacts the allocation of water in our economy. Water is a critical input for a number of sectors; from our basic sustenance to agriculture production, from industrial processes to ecological services, and from mineral extraction to energy production. Meanwhile, the supply of water is highly variable across space and through time while pollutants can further diminish the useable extent, making the policies to allocate and manage the resource central to understanding how the resource is utilized. The course will survey topics across sectors and water sources while applying economic theory and empirical/policy analysis. Prerequisite: EBGN509 or MATH213 or GEGN580. 3 hours lecture; 3 semester hours.

**EBGN540. ACCOUNTING AND FINANCE. 3.0 Semester Hrs.**

(I) Included are the relevant theories associated with capital budgeting, financing decisions, and dividend policy. This course provides an in-depth study of the theory and practice of corporate accounting and financial management including a study of the firm's objectives, investment decisions, long-term financing decisions, and working capital management. Preparation and interpretation of financial statements and the use of this financial information in evaluation and control of the organization. 3 hours lecture; 3 semester hours.

**EBGN541. INTERNATIONAL TRADE. 3.0 Semester Hrs.**

Theories and evidence on international trade and development. Determinants of static and dynamic comparative advantage. The arguments for and against free trade. Economic development in nonindustrialized countries. Sectoral development policies and industrialization. The special problems and opportunities created by extensive mineral resource endowments. The impact of value-added processing and export diversification on development. Prerequisites: Principles of Microeconomics, MATH111, EBGN509, EBGN511.

**EBGN542. ECONOMIC DEVELOPMENT. 3.0 Semester Hrs.**

Role of energy and minerals in the development process. Sectoral policies and their links with macroeconomic policies. Special attention to issues of revenue stabilization, resource largesse effects, downstream processing, and diversification. Prerequisites: Principles of Microeconomics, MATH111, EBGN509, EBGN511, EBGN512.

**EBGN546. INVESTMENT AND PORTFOLIO MANAGEMENT. 3.0 Semester Hrs.**

This course covers institutional information, valuation theory and empirical analysis of alternative financial investments, including stocks, bonds, mutual funds, ETS, and (to a limited extent) derivative securities. Special attention is paid to the role of commodities (esp. metals and energy products) as an alternative investment class. After an overview of time value of money and arbitrage and their application to the valuation of stocks and bonds, there is extensive treatment of optimal portfolio selection for risk averse investors, mean-variance efficient portfolio theory, index models, and equilibrium theories of asset pricing including the capital asset pricing model (CAPM) and arbitrage pricing theory (APT). Market efficiency is discussed, as are its implications for passive and active approaches to investment management. Investment management functions and policies, and portfolio performance evaluation are also considered. Prerequisites: Principles of Microeconomics, MATH111, MATH530.

**EBGN547. FINANCIAL RISK MANAGEMENT. 3.0 Semester Hrs.**

Analysis of the sources, causes and effects of risks associated with holding, operating and managing assets by individuals and organizations; evaluation of the need and importance of managing these risks; and discussion of the methods employed and the instruments utilized to achieve risk shifting objectives. The course concentrates on the use of derivative assets in the risk management process. These derivatives include futures, options, swaps, swaptions, caps, collars and floors. Exposure to market and credit risks will be explored and ways of handling them will be reviewed and critiqued through analysis of case studies from the mineral and energy industries. Prerequisites: Principles of Microeconomics, MATH111, MATH530, EBGN505; EBGN545 or EBGN546. Recommended: EBGN509, EBGN511.

**EBGN553. PROJECT MANAGEMENT. 3.0 Semester Hrs.**

(I, II) Project management has evolved into a business process broadly used in organizations to accomplish goals and objectives through teams. This course covers the essential principles of traditional project management consistent with professional certification requirements (the Project Management Institute's PMP certification) as well as an introduction to current agile project management methodologies. The traditional project management phases of project initiation, planning, execution, monitoring and control, and project closure are covered including related scheduling, estimating, risk assessment and other analytical tools. Students will gain experience using Microsoft Project. Organizational structure and culture issues are analyzed to understand how they can impact project management success, and the concepts of project portfolios and project programs are applied from the organizational perspective. Agile project management methodologies are introduced, including adaptive and iterative processes, scrum, lean and other agile tools and techniques. By the end of the course, students will understand how traditional and agile project. 3 hours lecture; 3 semester hours.

**EBGN555. LINEAR PROGRAMMING. 3.0 Semester Hrs.**

This course addresses the formulation of linear programming models, examines linear programs in two dimensions, covers standard form and other basics essential to understanding the Simplex method, the Simplex method itself, duality theory, complementary slackness conditions, and sensitivity analysis. As time permits, multi-objective programming and stochastic programming are introduced. Applications of linear programming models discussed in this course include, but are not limited to, the areas of manufacturing, finance, energy, mining, transportation and logistics, and the military. Prerequisite: MATH111; MATH332 or EBGN509. 3 hours lecture; 3 semester hours.

**EBGN559. SUPPLY CHAIN MANAGEMENT. 3.0 Semester Hrs.**
The focus of the course is to show how a firm can achieve better ? supply-demand matching? through the implementation of rigorous mathematical models and various operational/tactical strategies. We look at organizations as entities that must match the supply of what they produce with the demand for their products. A considerable portion of the course is devoted to mathematical models that treat uncertainty in the supply-chain. Topics include managing economies of scale for functional products, managing market-mediation costs for innovative products, make-to order versus make-to-stock systems, quick response strategies, risk pooling strategies, supply-chain contracts and revenue management. Additional ?special topics? may be introduced, such as reverse logistics issues in the supply-chain or contemporary operational and financial hedging strategies, as time permits Prerequisites: MATH111, MATH530.

**EBGN560. DECISION ANALYTICS. 3.0 Semester Hrs.**
Introduction to the science of decision making and risk theory. Application of decision analysis and utility theory to the analysis of strategic decision problems. Focuses on the application of quantitative methods to business problems characterized by risk and uncertainty. Choice problems such as decisions concerning major capital investments, corporate acquisitions, new product introductions, and choices among alternative technologies are conceptualized and structured using the concepts introduced in this course.

**EBGN562. STRATEGIC DECISION MAKING. 3.0 Semester Hrs.**
(I, II, S) This course covers how to unwind complex situations to gain clarity and enable confident decisions. The focus is on thinking as opposed to calculating, framing the problem correctly, ensuring clarity around the objectives, developing creative alternative strategies, and qualitatively evaluating these alternatives. Tools for accomplishing these goals will be introduced. Discussion topics include common psychological biases and traps, scenario analysis, game theory, cultural influences, and decision making in complex (as opposed to merely complicated) systems. 3 hours lecture; 3 semester hours.

**EBGN563. MANAGEMENT OF TECHNOLOGY. 3.0 Semester Hrs.**
Case studies and reading assignments explore strategies for profiting from technology assets and technological innovation. The roles of strategy, core competencies, product and process development, manufacturing, R&D, marketing, strategic partnerships, alliances, intellectual property, organizational architectures, leadership and politics are explored in the context of technological innovation. The critical role of organizational knowledge and learning in a firm?s ability to leverage technological innovation to gain competitive advantage is explored. The relationships between an innovation, the competencies of the innovating firm, the ease of duplication of the innovation by outsiders, the nature of complementary assets needed to successfully commercialize an innovation and the appropriate strategy for commercializing the innovation are developed. Students explore the role of network effects in commercialization strategies, particularly with respect to standards wars aimed at establishing new dominant designs. Prerequisite: EBGN5043 recommended.

**EBGN565. MARKETING FOR TECHNOLOGY-BASED COMPANIES. 3.0 Semester Hrs.**
This class explores concepts and practices related to marketing in this unique, fast-paced environment, including the defining characteristics of high-technology industries; different types and patterns of innovations and their marketing implications; the need for (and difficulties in) adopting a customer-orientation; tools used to gather marketing research/intelligence in technology-driven industries; use of strategic alliances and partnerships in marketing technology; adaptations to the "4 P's"; regulatory and ethical considerations in technological arenas. Prerequisite: None.

**EBGN566. TECHNOLOGY ENTREPRENEURSHIP. 3.0 Semester Hrs.**
Introduces concepts related to starting and expanding a technological-based corporation. Presents ideas such as developing a business and financing plan, role of intellectual property, and the importance of a good R&D program. Prerequisite: None.

**EBGN567. BUSINESS LAW AND ETHICS. 3.0 Semester Hrs.**
(I) This course incorporates a broad range of legal topics and ethical issues relevant to technology-based organizations, from start-ups to mature Fortune 100 international corporations. The topics encompass numerous aspects of U.S. business law, including but not limited to: the U.S. court system, contracts, e-commerce, managerial ethics, white collar crimes, early stage business formation, intellectual property, product liability, agency law, employment law, mergers and acquisitions, antitrust, and unfair competition law. The course is discussion based, with some lecture, and is 3 semester credit hours. There are no prerequisites required for this course. A significant portion of class time will be applied to exploring and discussing assigned topics through relevant abbreviated court case descriptions, ethics reader assignments and current and recent events in global business. He overall goal of this course is not to make students legal experts but to make them better managers and leaders by equipping them with relevant legal. 3 hours lecture; 3 semester hours.

**EBGN568. ADVANCED PROJECT ANALYSIS. 3.0 Semester Hrs.**
An advanced course in economic analysis that will look at more complex issues associated with valuing investments and projects. Discussion will focus on development and application of concepts in after-tax environments and look at other criteria and their impact in the decision-making and valuation process. Applications to engineering and technology aspects will be discussed. Effective presentation of results will be an important component of the course. Prerequisite: EBGN504.

**EBGN570. ENVIRONMENTAL ECONOMICS. 3.0 Semester Hrs.**
The role of markets and other economic considerations in controlling pollution; the effect of environmental policy on resource allocation incentives; the use of benefit/cost analysis in environmental policy decisions and the associated problems with measuring benefits and costs. Prerequisites: Principles of Microeconomics, MATH111, EBGN509, EBGN510.

**EBGN571. MARKETING ANALYTICS. 3.0 Semester Hrs.**

(II) The purpose of this course is to gain an understanding of how data about customers and markets can be used to support and improve decision making. Using market data to evaluate alternatives and gain insight from past performance is the essence of marketing analytics. The course is focused on the marketing research decisions facing product managers in technology based companies and will appeal to students who want to gain a deeper understanding of such topics as the problems of target market selection, new product introductions, pricing, and customer retention. While the specifics of market analytics can vary across industries and firms, three main commonalities are: (1) defining the decision problem, (2) collection and analysis of high quality market data, and (3) implementing strategy through marketing mix decisions. In this course students will develop an understanding of available marketing analytic methods and the ability to use marketing research information to make strategic and tactical decisions. 3 hours lecture; 3 semester hours.

**EBGN572. INTERNATIONAL BUSINESS STRATEGY. 3.0 Semester Hrs.**

The purpose of this course is to gain understanding of the complexities presented by managing businesses in an international environment. International business has grown rapidly in recent decades due to technological expansion, liberalization of government policies on trade and resource movements, development of institutions needed to support and facilitate international transactions, and increased global competition. Due to these factors, foreign countries increasingly are a source of both production and sales for domestic companies. Prerequisite: None.

**EBGN573. ENTREPRENEURIAL FINANCE. 3.0 Semester Hrs.**

Entrepreneurial activity has been a potent source of innovation and job generation in the global economy. In the U.S., the majority of new jobs are generated by new entrepreneurial firms. The financial issues confronting entrepreneurial firms are drastically different from those of established companies. The focus in this course will be on analyzing the unique financial issues which face entrepreneurial firms and to develop a set of skills that has wide applications for such situations. Prerequisite: EBGN505. Corequisite: EBGN545.

**EBGN575. ADVANCED MINING AND ENERGY ASSET VALUATION. 3.0 Semester Hrs.**

(I) The use of option pricing techniques in mineral and energy asset valuation. Mining and energy valuation standards and guidelines. Differentiation between static decision making, intertemporal decision making, and dynamic decision making under uncertainty. The comparison sales and cost approaches to valuation. Commodity price simulation and price forecasting. Risk-neutral valuation. Prerequisites: EBGN504, EBGN509, EBGN510, EBGN511, EBGN521, EBGN590. 3 hours lecture; 3 semester hours.

**EBGN576. MANAGING AND MARKETING NEW PRODUCT DEVELOPMENTS. 3.0 Semester Hrs.**

(II) This course provides a scientific approach to developing and marketing new products which are often critical to the success of firms competing in technology based industries. We will start with an overview of core marketing and then develop prototypes of a new product design. We will step through the new product development process in detail, learning about available tools and techniques to execute each process step along the way. New product prototypes will be used to gather data from prospective target markets and assess the viability of the design in the marketplace. 3 hours lecture; 3 semester hours.

**EBGN577. LEADING & MANAGING HIGH PERFORMING TEAMS. 3.0 Semester Hrs.**

(I) Effective leaders contribute significantly to their organization?s performance. When they take advantage of a technological innovation or respond to a crisis, leaders rely on critical skills to communicate their vision and coordinate tasks performed by others. This course is about developing your unique leadership skills and style whether you lead a small engineering team or, eventually, a large global corporation. We review key theories of leadership and examine the lessons learned from those who applied them. We synthesize and translate these lessons into specific behaviors that enhance your ability to lead. We discuss how generational shifts, economic and political factors impact the workplace in ways that call for effective, quality leadership. Ultimately, you have to understand how to lead and motivate individuals who don't look or think like you. This may involve motivating followers and involving them in making decisions. Following a learning-by-doing approach, we complement class discussions and case studies with a hands-on simulation of a leadership team facing a series of crises. 3 hours lecture; 3 semester hours.

**EBGN578. OPERATIONS AND INFORMATION SYSTEMS. 3.0 Semester Hrs.**

Operations and Information Systems is a special topics course for ETM and approved undergrad students who wish to learn about how businesses work and the information systems (IS) that enable the business operations. Students will gain an understanding of the businesses that they will shortly be involved with as they start their first career positions. Hands-on exercises to learn how to design processes, trouble shoot operational problems with root cause analysis, and a manufacturing process simulation will be provided during the course. Key operations topics include: operations strategy and positioning, manufacturing process types, Lean Manufacturing, distribution, process design, productivity, optimization, control system theory, quality control, Total Quality Management (TQM), forecasting and capacity planning, and Six Sigma. Key information systems topics include: trends in information technology, applications, Enterprise Resource Planning (ERP), IS infrastructure, and an emphasis on cyber-security.

**EBGN580. EXPLORATION ECONOMICS. 3.0 Semester Hrs.**

Exploration planning and decision making for oil and gas, and metallic minerals. Risk analysis. Historical trends in exploration activity and productivity. Prerequisites: Principles of Microeconomics, EBGN510. Offered when student demand is sufficient.

**EBGN585. ENGINEERING AND TECHNOLOGY MANAGEMENT CAPSTONE. 3.0 Semester Hrs.**

This course represents the culmination of the ETM Program. This course is about the strategic management process ? how strategies are developed and imple mented in organizations. It examines senior management?s role in formulating strategy and the role that all an organization?s managers play in implementing a well thought out strategy. Among the topics discussed in this course are (1) how different industry conditions support different types of strategies; (2) how industry conditions change and the implication of those changes for strategic management; and (3) how organizations develop and maintain capabilities that lead to sustained competitive advantage. This course consists of learning fundamental concepts associated with strategic management process and competing in a web-based strategic management simulation to support the knowledge that you have developed. Prerequisites: MATH530, EBGN504.

**EBGN590. ECONOMETRICS I. 3.0 Semester Hrs.**
(II) This course covers the statistical methods used by economists to estimate economic relationships and empirically test economic theories. Topics covered include hypothesis testing, ordinary least squares, specification error, serial correlations, heteroskedasticity, qualitative and limited dependent variables, time series analysis and panel data. Prerequisites: MATH111, MATH530, EBGN509. 3 hours lecture and discussion; 3 semester hours.

**EBGN594. TIME-SERIES ECONOMETRICS. 3.0 Semester Hrs.**
(II) This is a course in applied time-series econometrics. It covers contemporary approaches for interpreting and analyzing time-series economic data. Hypothesis testing and forecasting both receive attention. Topics include stochastic difference equations, applied forecasting, stationary univariate models, models with constant and time-varying variance, deterministic and stochastic trend models and associated unit root and structural break tests, as well as single-equation and multiple-equation time-series models that include error-correction techniques and cointegration tests. 3 hours lecture; 3 semester hours.

**EBGN598. SPECIAL TOPICS IN ECONOMICS AND BUSINESS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**EBGN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**EBGN610. ADVANCED NATURAL RESOURCE ECONOMICS. 3.0 Semester Hrs.**
Optimal resource use in a dynamic context using mathematical programming, optimal control theory and game theory. Constrained optimization techniques are used to evaluate the impact of capital constraints, exploration activity and environmental regulations. Offered when student demand is sufficient. Prerequisites: Principles of Microeconomics, MATH111, MATH5301, EBGN509, EBGN510, EBGN511.

**EBGN611. ADVANCED MICROECONOMICS. 3.0 Semester Hrs.**
A second graduate course in microeconomics, emphasizing state-of-the-art theoretical and mathematical developments. Topics include consumer theory, production theory and the use of game theoretic and dynamic optimization tools. Prerequisites: Principles of Microeconomics, MATH111, MATH5301, EBGN509, EBGN511.

**EBGN632. PRIMARY FUELS. 3.0 Semester Hrs.**
(II) Application of models to understand markets for oil, gas, coal exploration and extraction. Empirical, theoretical and quantitative models and modeling techniques are stressed. The issues included are identification of cause and effect, market structure, game theory, futures markets, environmental issues, energy policy, energy regulation. The emphasis in the course is on the development of appropriate models and their application to current issues in primary fuel/upstream markets. Prerequisites: EBGN590. 3 hours lecture; 3 semester hours.

**EBGN645. COMPUTATIONAL ECONOMICS. 3.0 Semester Hrs.**
(II) This course is about learning the skills required to construct and manipulate numerical models as an instrument of economic research. In the first part of the course, students will learn about basic classes of optimization problems as ways to operationalize models of equilibrium behavior from economics and how to formulate and solve these problems on the computer. In the second part of the course, students will focus on the techniques used specifically in computable general equilibrium (CGE) analysis and developing applications of CGE models to topics in energy, environmental and natural resource economics. Prerequisites: MATH111, MATH530, Principles of Microeconomics, EBGN509, EBGN511. 3 hours lecture; 3 semester hours.

**EBGN655. ADVANCED LINEAR PROGRAMMING. 3.0 Semester Hrs.**
Equivalent with EBGN650,
As an advanced course in optimization, this course will expand upon topics in linear programming. Specific topics to be covered include advanced formulation, column generation, interior point method, stochastic optimization, and numerical stability in linear programming. Applications of state-of-the-art hardware and software will emphasize solving real-world problems in areas such as mining, energy, transportation and the military. Prerequisites: EBGN555. 3 hours lecture; 3 semester hours.

**EBGN690. ECONOMETRICS II. 3.0 Semester Hrs.**
A second course in econometrics. Compared to EBGN590, this course provides a more theoretical and mathematical understanding of econometrics. Matrix algebra is used and model construction and hypothesis testing are emphasized rather than forecasting. Prerequisites: Principles of Microeconomics, MATH111, MATH530, EBGN509, EBGN590. Recommended: EBGN511.

**EBGN695. RESEARCH METHODOLOGY. 3.0 Semester Hrs.**
Lectures provide an overview of methods used in economic research relating to EPP and QBA/OR dissertations in Mineral Economics and information on how to carry out research and present research results. Students will be required to write and present a research paper that will be submitted for publication. It is expected that this paper will lead to a Ph.D. dissertation proposal. It is a good idea for students to start thinking about potential dissertation topic areas as they study for their qualifier. This course is also recommended for students writing Master?s thesis or who want guidance in doing independent research relating to the economics and business aspects of energy, minerals and related environmental and technological topics. Prerequisites: MATH530, EBGN509, EBGN510, EBGN511, EBGN590.

**EBGN698. SPECIAL TOPICS IN ECONOMICS AND BUSINESS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**EBGN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**EBGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**

(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

## Professor

Roderick G. Eggert, Viola Vestal Coulter Professor

## Associate Professors

Jared C. Carbone

Michael B. Heeley

## Assistant Professors

Tulay Flamand

Ben Gilbert

Ian A. Lange

Peter Maniloff

Steven M. Smith

## Teaching Professor

Scott Houser

## Teaching Associate Professors

Becky Lafrancois

Andrew Pederson

Sid Saleh

## Professor of Practice

David Culbreth

## Professors Emeriti

Carol A. Dahl

Graham Davis

Franklin J. Stermole

John E. Tilton

Michael R. Walls

# Engineering, Design, and Society

## Degrees

- Master of Science in Humanitarian Engineering and Science (Thesis and Non-Thesis options)
- Graduate Certificate in Humanitarian Engineering and Science

## Program Description

The mission of the Division of Engineering, Design, and Society (EDS) is to engage in research, education, and outreach that inspires and empowers engineers and applied scientists to become innovative and impactful leaders in sociotechnical problem definition, solution, and design who can address the challenges of attaining a sustainable global society.

Information on the Humanitarian Engineering degree programs can be found in the Interdisciplinary Programs section of the catalog.

# Electrical Engineering

## Degrees Offered

- Master of Science (Electrical Engineering)
- Doctor of Philosophy (Electrical Engineering)
- Master of Science (Smart-Grid, Power Electronics, and Electrical Power Systems)
- Graduate Certificate in Smart-Grid, Power Electronics, and Electrical Power Systems
- Graduate Certificate in Data Science for Signals and Systems
- Graduate Certificate in Antennas and Radar Technology
- Graduate Certificate in RF & Microwave Engineering

## Program Overview

The Electrical Engineering Department offer the degrees Master of Science and Doctor of Philosophy in Electrical Engineering. These degree programs demand academic rigor and depth yet also address real-world problems.

The Department has three areas of research activity that stem from the core fields of Electrical Engineering: (1) Antennas and Wireless Communications, (2) Information and Systems Science and (3) Energy Systems and Power Electronics. Individual research projects may encompass more than one research area.

## Research Areas:

***Antennas and Wireless Communications*** is a research area that builds on the fundamental physics and mathematics of electromagnetic waves and propagation. The research in this area includes design, analysis, optimization, and measurement of antennas, antenna arrays, microwave, millimeter-wave, and terahertz devices. Applications address current academic, industry, and society needs, such as wireless communication systems, radar and remote sensing, and electromagnetic imaging.

***Information and Systems Sciences*** is an interdisciplinary research area that encompasses the fields of control systems, data science, optimization, signal and image processing, compressive sensing, robotics, and mechatronics. Applications can be found in renewable energy and power systems, materials processing, sensor and control networks, bio-engineering, computer vision and pattern recognition, autonomous systems, imaging, intelligent structures, and geosystems.

***Energy Systems and Power Electronics*** is focused on both fundamental and applied research in the interrelated fields of conventional electric power systems and electric machinery, renewable energy and distributed generation, energy economics and policy issues, power quality, power electronics and drives. The overall scope of research encompasses a broad spectrum of electrical energy applications including investor-owned utilities, rural electric associations, manufacturing facilities, regulatory agencies, and consulting engineering firms.

## Program Details

The Electrical Engineering Department offers the degrees Master of Science and Doctor of Philosophy in Electrical Engineering. The master's program is designed to prepare candidates for careers in industry or government or for further study at the PhD level; both thesis and non-thesis options are available. The PhD degree program is sufficiently flexible to prepare candidates for careers in industry, government, or academia. See the information that follows for full details on these four degrees.

## Mines Combined Undergraduate / Graduate Degree Program

The Electrical Engineering Department also offers combined BS/MS degree programs in three different tracks: (a) Information and Systems Sciences, (b) Energy Systems and Power Electronics, and (c) Antennas and Wireless Communications. These programs offer an expedited graduate school application process and allow students to begin graduate coursework while still finishing their undergraduate degree requirements. Students enrolled in Mine's Combined Undergraduate/Graduate Program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any courses that count towards the graduate degree requirements as either "Required Coursework" or "Elective Coursework", as defined below, may be used for the purposes of double counting at the discretion of the advisor (MS Non-Thesis) or thesis committee (MS Thesis or PhD). These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit.

## Prerequisites

*Requirements for Admission to EE:* The minimum requirements for admission to the MS and PhD degrees in Electrical Engineering are:

- A baccalaureate degree in engineering, computer science, a physical science, or math with a grade-point average of 3.0 or better on a 4.0 scale.
- Graduate Record Examination (Quantitative section) score of 151 or higher (or 650 on the old scale). Applicants who have graduated with an engineering degree from Mines within the past five years are not required to submit GRE scores.
- TOEFL score of 79 or higher (or 550 for the paper-based test or 213 for the computer-based test) for applicants whose native language is not English. In lieu of a TOEFL score, and IELTS score of 6.5 or higher will be accepted.
- For the PhD program, prior research experience is desired but not required.

*Admitted Students:* The EE Department Graduate Committee may require that an admitted student take undergraduate remedial coursework to overcome technical deficiencies. The committee will decide whether to recommend regular or provisional admission.

*Transfer Courses:* Graduate level courses taken at other universities for which a grade equivalent to a "B" or better was received will be considered for transfer credit with approval of the Advisor and/or Thesis Committee, and EE Department Head, as appropriate.  Transfer credits must not have been used as credit toward a Bachelor degree. For the MS degree, no more than nine credits may transfer. For the PhD degree, up to 24 credit hours may be transferred. In lieu of transfer credit for individual courses, students who enter the PhD program with a thesis-based master's degree from another institution may transfer up to 36 hours in recognition of the course work and research completed for that degree.

*400-level Courses:* As stipulated by the Mines Graduate School, students may apply toward graduate degree requirements a maximum of nine (9.0) semester hours of department-approved 400-level course work.

*Advisor and Thesis Committee:* Students must have an Advisor from the EE faculty to direct and monitor their academic plan, research, and independent studies. Advisors must be full-time permanent members of the faculty. In this context, full-time permanent members of the faculty are those that hold the rank of professor, associate professor, assistant professor, research professor, associate research professor or assistant research professor. Upon approval by the Graduate Dean, adjunct faculty, teaching faculty, visiting professors, emeritus professors and off-campus representatives may be designated additional co-advisors. A list of EE faculty by rank is available in the faculty tab in the catalog.

> Master of Science (thesis option) students must have at least three members on their Thesis Committee; the Advisor and one other member must be permanent faculty in the EE Department. Students who choose to have a minor program must select a representative from the minor area of study to serve on the Thesis Committee. PhD Thesis Committees must have at least four members; the Advisor and two additional members must be permanent faculty in the EE Department, and one member must be outside the departmental faculty and serving as chair of the committee. Students who choose to have a minor program must select a representative from the minor area of study to serve on the Thesis Committee.

*Degree Audit and Admission to Candidacy:* All degree students must submit required forms by the deadlines posted by the Office of Graduate Studies

> Master students must complete the Degree Audit form (http://gradschool.mines.edu/Degree-Audit/) by the posted deadline. PhD students need to submit the Degree Audit form (http://gradschool.mines.edu/Degree-Audit/) by the posted deadline and need to submit the Admission to Candidacy form (https://inside.mines.edu/GS-Candidacy-Addendum/) by the first day of the semester in which they want to be considered eligible for reduced registration.

*Time Limit:* As stipulated by the Mines Graduate School, a candidate for a Masters degree must complete all requirements for the degree within five years of the date of admission into the degree program. A candidate for a doctoral degree must complete all requirements for the degree within nine years of the date of admission into the degree program.

## Program Requirements

## Master of Science – Electrical Engineering

The MS degree in Electrical Engineering (Thesis or Non-Thesis Option) requires 30 credit hours. All MS students are also required to enroll in the zero-credit course EENG 500 Graduate Seminar each semester . Requirements for the thesis MS are 24 hours of coursework and six credit hours of thesis research. The non-thesis option requires 30 credit hours of coursework. A maximum of six credit hours of  Independent Study can be used to fulfill degree requirements. There are three tracks in Electrical Engineering: (1) Antennas and Wireless Communications (AWC), (2) Energy Systems and Power Electronics (ESPE), and (3) Information and Systems Sciences (ISS). Students are encouraged to decide between tracks before pursuing an advanced degree. Students are also encouraged to speak to their Advisor and/or a member of the EE faculty before registering for classes and to select a permanent Advisor as soon as possible. The following set of courses is required of all students.

## MS Thesis - Electrical Engineering

| | | |
|---|---|---|
| EENG707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 6.0 |
| EENG500 | GRADUATE SEMINAR (All tracks) Enrollment required every fall and spring semester | 0.0 |
| EE CORE: EE Core Courses (AWC track) | | 9.0 |
| EE CORE: EE Core Courses (ESPE track) | | 0.0 |
| EE CORE: EE Core Courses (ISS track) | | 12.0 |
| TECHNICAL ELECTIVES Technical Electives must be approved by Thesis Committee | | |
| EE TECH: EE Technical Electives (AWC track) | | 15.0 |
| EE TECH: EE Technical Electives (ESPE track) | | 24.0 |
| EE TECH: EE Technical Electives (ISS track) | | 12.0 |

*MS Thesis Defense:* At the conclusion of the MS (Thesis Option), the student will be required to make a formal presentation and defense of her/his thesis research.

## MS Non-Thesis - Electrical Engineering

| | | |
|---|---|---|
| EENG500 | GRADUATE SEMINAR (All tracks) Enrollment required every fall and spring semester | 0.0 |
| EE CORE: EE Core Courses (AWC track) | | 9.0 |
| EE CORE: EE Core Courses (ESPE track) | | 0.0 |
| EE CORE: EE Core Courses (ISS track) | | 12.0 |
| TECHNICAL ELECTIVES Technical Electives must be approved by Advisor | | |
| EE TECH: EE Technical Electives (AWC track) | | 15.0 |
| EE TECH: EE Technical Electives (ESPE track) | | 24.0 |
| EE TECH: EE Technical Electives (ISS track) | | 12.0 |
| EE Electives (all tracks) Must be taught by an approved faculty member in EE | | 6.0 |

## Doctor of Philosophy - Electrical Engineering

The PhD degree in Electrical Engineering requires 72 credit hours of course work and research credits. A minimum of 36 credit hours of course work and a minimum of 24 credit hours of research is required. The remaining 12 credit hours required can be earned through research or coursework and students should consult with their Advisor and/or Thesis Committee. The students are also required to enroll in the zero-credit course EENG 500 Graduate Seminar each semester. There are three tracks in Electrical Engineering: (1) Antennas and Wireless Communications (AWC), (2) Energy Systems and Power Electronics (ESPE), and (3) Information and Systems Sciences (ISS). Students are encouraged to decide between tracks before pursuing an advanced degree. Students are also encouraged to speak to their Advisor and/or a member of the EE faculty before registering for classes and to select a permanent Advisor as soon as possible. The following set of courses is required of all students.

| | | |
|---|---|---|
| EENG707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 24.0 |
| EENG500 | GRADUATE SEMINAR (All tracks) Enrollment required every fall and spring semester | 0.0 |
| EE CORE: EE Core Courses (AWC track) | | 9.0 |
| EE CORE: EE Core Courses (ESPE track) | | 0.0 |
| EE CORE: EE Core Courses (ISS track) | | 12.0 |

| EE Technical Electives Technical Electives must be approved by Thesis Committee | |
|---|---|
| EE TECH: EE Technical Electives (AWC track) | 27.0 |
| EE TECH: EE Technical Electives (ESPE track) | 36.0 |
| EE TECH: EE Technical Electives (ISS track) | 24.0 |

## PhD Qualifying Examination

Students wishing to enroll in the Electrical Engineering PhD program will be required to pass a Qualifying Exam. Normally, full-time PhD candidates will take the Qualifying Exam in their first year, but it must be taken within four semesters of entering the program. Part-time candidates will normally be expected to take the Qualifying Exam within no more than six semesters of entering the program.

The purpose of the Qualifying Exam is to assess some of the attributes expected of a successful PhD student, including:

- To determine the student's ability to review, synthesize and apply fundamental concepts.
- To determine the creative and technical potential of the student to solve open-ended and challenging problems.
- To determine the student's technical communication skills.

The Qualifying Examination includes both written and oral sections. The written section is based on material from the EE Department's undergraduate Electrical Engineering degree. The oral part of the exam covers one or more papers from the literature chosen by the student and the student's Advisor. The student's Advisor and two additional Electrical Engineering faculty members (typically from the student's Thesis Committee representing their track) administer the oral exam.

PhD Qualifying exams will be held each spring semester. In the event of a student failing the Qualifying exam, she/he will be given one further opportunity to pass the exam in the following spring semester. If a second failure occurs, the student has unsatisfactory academic performance that results in an immediate, mandatory dismissal of the graduate student from the PhD program.

## PhD Thesis Proposal

After passing the Qualifying Examination, the PhD student is allowed up to 18 months to prepare a written Thesis Proposal and present it formally to the student's graduate committee and other interested faculty.

*Admission to Candidacy:* In addition to the Graduate School requirements, full-time students must complete the following requirements within two calendar years of enrolling in the PhD program.

- Have a Thesis Committee appointment form on file in the Graduate Office:
- Have passed the PhD Qualifying Exam demonstrating adequate preparation for, and satisfactory ability to conduct doctoral research.

## PhD Thesis Defense

At the conclusion of the student's PhD program, the student will be required to make a formal presentation and defense of her/his thesis research. The EE department enforces a defense policy for PhD students with regards to their publications and presentations. According to this policy, the required and recommended publications and presentations for EE PhD students before graduation are listed below:

- Journal Publications
  - Required: Minimum of one first-author paper accepted or published in a peer-reviewed journal before the Dissertation Defense.
  - Recommended: Three or more first-author papers accepted or published in peer-reviewed journals. More than three first-author journal publications are recommended for students interested in academic positions.
- Presentations
  - Required: Minimum of one research presentation (poster or oral presentation) before the Dissertation Defense. Possible venues include an external technical conference, the campus-wide graduate student research conference, the departmental colloquium, or a sponsor meeting.
  - Recommended: Two or more research presentations at external technical conferences where the student is the first author on the presented work. Numerous conference presentations are strongly encouraged to establish a research reputation for students interested in academic positions.
- Exceptions: Students wanting to defend before meeting these requirements must submit a 1-page petition with reasonable explanation to the EE Graduate Committee. Certain conferences, particularly some related to Computer Science, publish longer papers and have high standards for acceptance and thus may be considered as journal-quality. Finally, while some journals may have lengthy review timelines and thus some students may wish to defend their dissertation while a journal paper is still under review, students should be aware that peer review comments and final decisions provide valuable input to a dissertation committee in assessing a student's research. Reviews from intermediate conference publications can help in assessing a recent journal submission.
- MS thesis students: It is recommended that students pursuing a thesis-based MS degree have submitted at least one paper to a peer-reviewed journal or conference and given at least one research presentation (poster or oral presentation) before the Dissertation Defense.

**Electrical Engineering Courses**

***Required Core: Antennas and Wireless Communications Track***

All students must take three of the following five core courses.

| | | |
|---|---|---|
| EENG525 | ANTENNAS | 3.0 |
| EENG526 | ADVANCED ELECTROMAGNETICS | 3.0 |
| EENG527 | WIRELESS COMMUNICATIONS | 3.0 |
| EENG528 | COMPUTATIONAL ELECTROMAGNETICS | 3.0 |
| EENG530 | PASSIVE RF & MICROWAVE DEVICES | 3.0 |

***Required Core: Energy Systems and Power Electronics Track***

There is no core course requirement for the ESPE track.

***Required Core: Information and Systems Sciences Track***

All students must take:

| | | |
|---|---|---|
| EENG515 | MATHEMATICAL METHODS FOR SIGNALS AND SYSTEMS | 3.0 |

and choose at least three of the following:

| | | |
|---|---|---|
| EENG509 | SPARSE SIGNAL PROCESSING | 3.0 |
| EENG511 | CONVEX OPTIMIZATION AND ITS ENGINEERING APPLICATIONS | 3.0 |
| EENG517 | THEORY AND DESIGN OF ADVANCED CONTROL SYSTEMS | 3.0 |
| EENG519 | ESTIMATION THEORY AND KALMAN FILTERING | 3.0 |
| EENG527 | WIRELESS COMMUNICATIONS | 3.0 |
| EGGN589 | DESIGN AND CONTROL OF WIND ENERGY SYSTEMS | 3.0 |
| MEGN544 | ROBOT MECHANICS: KINEMATICS, DYNAMICS, AND CONTROL | 3.0 |

## Program Requirements

## Renewable Energy, Utility Integration, and Smart-Grid Technology

## Graduate Certificate in Smart-Grid, Power Electronics, and Electrical Power Systems

The Certificate 'Smart-Grid, Power Electronics, and Electrical Power Systems' is targeted to train recent graduates or mid-career professionals with a BS in electrical engineering. To earn a Graduate Certificate in Smart-Grid, Power Electronics, and Electrical Power Systems, students must complete 12 hours of coursework as follows:

| | | |
|---|---|---|
| EENG475 | INTERCONNECTION OF RENEWABLE ENERGY, INTEGRATED POWER ELECTRONICS, POWER SYSTEMS, AND POWER QUALITY | 3.0 |
| EENG577 | ADVANCED ELECTRICAL MACHINE DYNAMICS FOR SMART-GRID SYSTEMS | 3.0 |
| EENG588 | ENERGY POLICY, RESTRUCTURING AND DEREGULATION OF ELECTRICITY MARKET | 3.0 |
| EENG Elective from the list | | 3.0 |
| Total Semester Hrs | | 12.0 |

**Elective List for Graduate Certificate:**

| | | |
|---|---|---|
| EENG572 | RENEWABLE ENERGY AND DISTRIBUTED GENERATION | 3.0 |
| EENG582 | HIGH VOLTAGE AC AND DC POWER TRANSMISSION | 3.0 |
| EENG586 | COMMUNICATION NETWORKS FOR POWER SYSTEMS | 3.0 |
| EENG587 | POWER SYSTEMS PROTECTION AND RELAYING | 3.0 |

## Master of Science in Smart-Grid, Power Electronics, and Electrical Power Systems

| | | |
|---|---|---|
| EENG475 | INTERCONNECTION OF RENEWABLE ENERGY, INTEGRATED POWER ELECTRONICS, POWER SYSTEMS, AND POWER QUALITY | 3.0 |
| EENG577 | ADVANCED ELECTRICAL MACHINE DYNAMICS FOR SMART-GRID SYSTEMS | 3.0 |
| EENG588 | ENERGY POLICY, RESTRUCTURING AND DEREGULATION OF ELECTRICITY MARKET | 3.0 |
| EENG600 | GRADUATE SEMINAR ON SMART-GRID ELECTRICAL POWER AND ENERGY SYSTEMS | 3.0 |
| EENG5XX | Engineering Core Course From List | 6.0 |
| EENG707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 6.0 |
| EENG5XX or EENG4XX | Electrical Engineering Coursework (6 credits) as approved by the Advisor, the total # of 400-level courses as allowed by the Mines Graduate Program guidelines | 6.0 |
| Total Semester Hrs | | 30.0 |

**Core Courses List - Choose six credit hours with the approval of your advisor.**

| | | |
|---|---|---|
| EENG570 | ADVANCED HIGH POWER ELECTRONICS | 3.0 |
| EENG571 | MODERN ADJUSTABLE SPEED ELECTRIC DRIVES | 3.0 |
| EENG572 | RENEWABLE ENERGY AND DISTRIBUTED GENERATION | 3.0 |
| EENG582 | HIGH VOLTAGE AC AND DC POWER TRANSMISSION | 3.0 |
| EENG587 | POWER SYSTEMS PROTECTION AND RELAYING | 3.0 |
| EENG589 | DESIGN AND CONTROL OF WIND ENERGY SYSTEMS | 3.0 |

The Master's Committee is made up of three members, two of which must be from the home department.

## Master of Science in Smart-Grid, Power Electronics, and Electrical Power Systems (Non-Thesis)

| | | |
|---|---|---|
| EENG475 | INTERCONNECTION OF RENEWABLE ENERGY, INTEGRATED POWER ELECTRONICS, POWER SYSTEMS, AND POWER QUALITY | 3.0 |
| EENG570 | ADVANCED HIGH POWER ELECTRONICS | 3.0 |
| EENG572 | RENEWABLE ENERGY AND DISTRIBUTED GENERATION | 3.0 |
| EENG577 | ADVANCED ELECTRICAL MACHINE DYNAMICS FOR SMART-GRID SYSTEMS | 3.0 |
| EENG582 | HIGH VOLTAGE AC AND DC POWER TRANSMISSION | 3.0 |
| EENG587 | POWER SYSTEMS PROTECTION AND RELAYING | 3.0 |
| EENG588 | ENERGY POLICY, RESTRUCTURING AND DEREGULATION OF ELECTRICITY MARKET | 3.0 |
| EENG5XX | Engineering Core Course from List | 3.0 |
| EENG5XX or EENG4XX | Electrical Engineering Coursework (6 credits) as approved by the Advisor, the total # of 400-level courses as allowed by the Mines Graduate Program guidelines | 6.0 |
| Total Semester Hrs | | 30.0 |

Core Courses List - Choose three credit hours with the approval of your advisor.

| | | |
|---|---|---|
| EENG571 | MODERN ADJUSTABLE SPEED ELECTRIC DRIVES | 3.0 |
| EENG589 | DESIGN AND CONTROL OF WIND ENERGY SYSTEMS | 3.0 |
| EENG600 | GRADUATE SEMINAR ON SMART-GRID ELECTRICAL POWER AND ENERGY SYSTEMS | 3.0 |

The Non-Thesis Master's student has an advisor who is assigned to assist the student in interdisciplinary projects.

## Program Requirements

## Graduate Certificates

### Certificate #1: Graduate Certificate in Data Science for Signals and Systems

The graduate certificate program in Data Science for Signals and Systems is targeted to train recent graduates or mid-career professionals with a BS in electrical engineering or a related field in mathematical and algorithmic aspects of data science relevant for electrical engineers, specifically for handling the signals and data that are processed and created by modern physical and virtual electrical systems.

To earn the graduate certificate in Data Science for Signals and Systems, students must complete 12 hours of coursework as follows:

***Required Courses:***

| | | |
|---|---|---|
| EENG415 | DATA SCIENCE FOR ELECTRICAL ENGINEERING | 3.0 |
| EENG515 | MATHEMATICAL METHODS FOR SIGNALS AND SYSTEMS | 3.0 |

***Choose 2 out of 5:***

| | | |
|---|---|---|
| EENG509 | SPARSE SIGNAL PROCESSING | 3.0 |
| EENG511 | CONVEX OPTIMIZATION AND ITS ENGINEERING APPLICATIONS | 3.0 |
| EENG519 | ESTIMATION THEORY AND KALMAN FILTERING | 3.0 |
| EENG521 | NUMERICAL OPTIMIZATION | 3.0 |
| EENG586 | COMMUNICATION NETWORKS FOR POWER SYSTEMS | 3.0 |

### Certificate #2: Graduate Certificate in Antennas and Radar Technology

The graduate certificate program in Antennas and Radar Technology is targeted to train recent graduates or mid-career professionals with a Bachelor of Science degree in electrical engineering or a related field in physics or applied sciences with a basic knowledge of electromagnetic theory, specifically to handle the challenges and rising demands of advanced technologies related to modern antenna and Radar systems.

To earn the graduate certificate in Antennas and Radar Technology, participants must complete the following 12 hours of coursework:

| | | |
|---|---|---|
| EENG486 | ELECTROMAGNETIC FIELDS AND WAVES | 3.0 |
| EENG525 | ANTENNAS | 3.0 |
| EENG528 | COMPUTATIONAL ELECTROMAGNETICS | 3.0 |
| EENG540 | INTRODUCTION TO RADAR SYSTEMS | 3.0 |

### Certificate #3: Graduate Certificate in RF & Microwave Engineering

The graduate certificate program in RF and Microwave Engineering is targeted to train recent graduates or mid-career professionals with a BS in electrical engineering or a related field in physics or applied sciences with a basic knowledge of electromagnetic theory, specifically for handling the challenges and demands of modern microwave systems and Internet of Things devices.

To earn the graduate certificate in RF and Microwave Engineering, students must complete 12 hours of coursework as follows:

***Required Courses:***

| | | |
|---|---|---|
| EENG486 | ELECTROMAGNETIC FIELDS AND WAVES | 3.0 |
| EENG530 | PASSIVE RF & MICROWAVE DEVICES | 3.0 |

***Choose 2 out of 3:***

| | | |
|---|---|---|
| EENG529 | ACTIVE RF & MICROWAVE DEVICES | 3.0 |
| EENG531 | ACTIVE NONLINEAR RF & MICROWAVE DEVICES | 3.0 |
| EENG525 | ANTENNAS | 3.0 |

## Courses

**EENG500. GRADUATE SEMINAR. 0.0 Semester Hrs.**

This zero-credit graduate course builds on the EE department seminars in the colloquium series, which consist of presentations delivered by external or internal invited speakers on topics broadly related to electrical engineering. The seminar is mandatory for all graduate students (MS and Ph.D.). The students would need to enroll in the course every semester. Any student who cannot take the course for valid reasons should notify their adviser, who will then make a request to the EE graduate committee for a waiver. These requests could be for the duration of one semester or longer. The course will be graded as PRG/PRU based on student attendance at the department seminars in the colloquium series - the student has to attend at least two thirds of all the seminars each semester in order to get a PRG grade.

**EENG507. INTRODUCTION TO COMPUTER VISION. 3.0 Semester Hrs.**

Equivalent with CSCI507,CSCI512,EENG512,

(I) Computer vision is the process of using computers to acquire images, transform images, and extract symbolic descriptions from images. This course provides an introduction to this field, covering topics in image formation, feature extraction, location estimation, and object recognition. Design ability and hands-on projects will be emphasized, using popular software tools. The course will be of interest both to those who want to learn more about the subject and to those who just want to use computer imaging techniques. Prerequisites: Undergraduate level knowledge of linear algebra, statistics, and a programming language. 3 hours lecture; 3 semester hours.

**EENG508. ADVANCED TOPICS IN PERCEPTION AND COMPUTER VISION. 3.0 Semester Hrs.**

Equivalent with CSCI508,

(II) This course covers advanced topics in perception and computer vision, emphasizing research advances in the field. The course focuses on structure and motion estimation, general object detection and recognition, and tracking. Projects will be emphasized, using popular software tools. Prerequisites: EENG507 or CSCI507. 3 hours lecture; 3 semester hours.

**EENG509. SPARSE SIGNAL PROCESSING. 3.0 Semester Hrs.**

(II) This course presents a mathematical tour of sparse signal representations and their applications in modern signal processing. The classical Fourier transform and traditional digital signal processing techniques are extended to enable various types of computational harmonic analysis. Topics covered include time-frequency and wavelet analysis, filter banks, nonlinear approximation of functions, compression, signal restoration, and compressive sensing. Prerequisites: EENG411 and EENG515. 3 hours lecture; 3 semester hours.

**EENG511. CONVEX OPTIMIZATION AND ITS ENGINEERING APPLICATIONS. 3.0 Semester Hrs.**

The course focuses on recognizing and solving convex optimization problems that arise in applications in various engineering fields. Covered topics include basic convex analysis, conic programming, duality theory, unconstrained optimization, and constrained optimization. The application part covers problems in signal processing, power and energy, machine learning, control and mechanical engineering, and other fields, with an emphasis on modeling and solving these problems using the CVX package. Offered Spring semester of even years. Prerequisites: EENG311, EENG515.

**EENG515. MATHEMATICAL METHODS FOR SIGNALS AND SYSTEMS. 3.0 Semester Hrs.**

(I) An introduction to mathematical methods for modern signal processing using vector space methods. Topics include signal representation in Hilbert and Banach spaces; linear operators and the geometry of linear equations; LU, Cholesky, QR, eigen- and singular value decompositions. Applications to signal processing and linear systems are included throughout, such as Fourier analysis, wavelets, adaptive filtering, signal detection, and feedback control.

**EENG517. THEORY AND DESIGN OF ADVANCED CONTROL SYSTEMS. 3.0 Semester Hrs.**

(II) This course will introduce and study the theory and design of multivariable and nonlinear control systems. Students will learn to design multivariable controllers that are both optimal and robust, using tools such as state space and transfer matrix models, nonlinear analysis, optimal estimator and controller design, and multi-loop controller synthesis. Spring semester of even years. Prerequisites: EENG417. 3 hours lecture; 3 semester hours.

**EENG519. ESTIMATION THEORY AND KALMAN FILTERING. 3.0 Semester Hrs.**

(II) Estimation theory considers the extraction of useful information from raw sensor measurements in the presence of signal uncertainty. Common applications include navigation, localization and mapping, but applications can be found in all fields where measurements are used. Mathematic descriptions of random signals and the response of linear systems are presented. The discrete-time Kalman Filter is introduced, and conditions for optimality are described. Implementation issues, performance prediction, and filter divergence are discussed. Adaptive estimation and nonlinear estimation are also covered. Contemporary applications will be utilized throughout the course. Offered in odd numbered years. Prerequisites: EENG515. 1.5 hours lecture; 1.5 hours other; 3 semester hours.

**EENG521. NUMERICAL OPTIMIZATION. 3.0 Semester Hrs.**

Optimization is an indispensable tool for many fields of science and engineering. This course focuses on the algorithmic aspects of optimization. Covered topics include first-order (gradient descent and its variants) and second-order methods (Newton and quasi-Newton methods) for unconstrained optimization, theory and algorithms for constrained optimization, stochastic optimization and random search, derivative-free optimization, dynamic programming and simulation-based optimization, and distributed and parallel optimization. The emphasis will be on how the algorithms work, why they work, how to implement them numerically, and when to use which algorithm, as well as applications in different science and engineering fields. Prerequisite: EENG515 or instructor consent.

**EENG525. ANTENNAS. 3.0 Semester Hrs.**

(I, II) This course provides an in depth introduction to the analysis and synthesis of antennas and antenna arrays. Students are expected to use MATLAB to model antennas and their performance. An extensive final project that involves experimental or computer demonstrations is required. EENG525 has more depth and required work than EENG425. EENG525 students will have one additional problem for each homework assignment, one additional problem on exam, more difficult paper to review and present, and higher expectations on antenna and direction finding projects. Prerequisites: EGGN386 or GPGN302 or PHGN384. 3 hours lecture; 3 semester hours.

**EENG526. ADVANCED ELECTROMAGNETICS. 3.0 Semester Hrs.**

(II) In this course the fundamental theorems of electromagnetics are developed rigorously. Wave solutions are developed in Cartesian, cylindrical, and spherical coordinate systems for bounded and unbounded regions. Prerequisite: EENG386. 3 hours lecture; 3 semester hours.

**EENG527. WIRELESS COMMUNICATIONS. 3.0 Semester Hrs.**

Equivalent with EENG513,

(I, II) This course provides the tools needed to analyze and design a wireless system. Topics include link budgets, satellite communications, cellular communications, handsets, base stations, modulation techniques, RF propagation, coding, and diversity. Students are expected to complete an extensive final project. EENG527 has more depth and required work than EENG427. EENG527 students will have one additional problem for each homework assignment, one additional problem on exam, more difficult paper to review and present, and higher expectations on final project. Prerequisites: EENG386, EENG311, and EENG388. 3 hours lecture, 3 semester hours.

**EENG528. COMPUTATIONAL ELECTROMAGNETICS. 3.0 Semester Hrs.**
This course provides the basic formulation and numerical solution for static electric problems based on Laplace, Poisson and wave equations and for full wave electromagnetic problems based on Maxwell's equations. Variation principles methods, including the finite-element method and method of moments will be introduced. Field to circuit conversion will be discussed via the transmission line method. Numerical approximations based on the finite difference and finite difference frequency domain techniques will also be developed for solving practical problems. Prerequisite: EENG386.

**EENG529. ACTIVE RF & MICROWAVE DEVICES. 3.0 Semester Hrs.**
(II) This course introduces the basics of active radio-frequency (RF) and microwave circuits and devices which are the building blocks of modern communication and radar systems. The topics that will be studied are RF and microwave circuit components, resonant circuits, matching networks, noise in active circuits, switches, RF and microwave transistors and amplifiers. Additionally, mixers, oscillators, transceiver architectures, RF and monolithic microwave integrated circuits (RFICs and MMICs) will be introduced. Moreover, students will learn how to model active devices using professional CAD software, how to fabricate printed active microwave devices, how a vector network analyzer (VNA) operates, and how to measure active RF and microwave devices using VNAs. Prerequisites: EEBG385. 3 hours lecture; 3 semester hours.

**EENG530. PASSIVE RF & MICROWAVE DEVICES. 3.0 Semester Hrs.**
(I) This course introduces the basics of passive radio-frequency (RF) and microwave circuits and devices which are the building blocks of modern communication and radar systems. The topics that will be studied are microwave transmission lines and waveguides, microwave network theory, microwave resonators, power dividers, directional couplers, hybrids, RF/microwave filters, and phase shifters. Students will also learn how to design and analyze passive microwave devices using professional CAD software. Moreover, students will learn how to fabricate printed passive microwave devices and test them using a vector network analyzer. Prerequisites: EENG386. 3 hours lecture; 3 semester hours.

**EENG531. ACTIVE NONLINEAR RF & MICROWAVE DEVICES. 3.0 Semester Hrs.**
(II) This course introduces the basics of active nonlinear radio-frequency (RF) and microwave circuits and devices which are the building blocks of modern communication and radar systems. The topics that will be introduced are nonlinear phenomenon and related analysis and design techniques such as harmonic balance and Volterra series. Students will then apply this knowledge to design, analyze, fabricate, and test several nonlinear devices such as rectifiers, power amplifiers, oscillators, and mixers. Students will learn how to design and analyze these devices using professional CAD software and how to measure active nonlinear RF and microwave devices using VNAs. Offered every other year. Prerequisite: EENG282, EENG385. 3 hours lecture; 3 semester hours.

**EENG532. LOW TEMPERATURE MICROWAVE MEASUREMENTS FOR QUANTUM ENGINEERING. 3.0 Semester Hrs.**
The goal of the course is to provide hands on training in high-frequency, low-temperature measurements which are requisite for quantum information applications. This course introduces the fundamentals of high-frequency measurements, the latest techniques for accuracy-enhanced automated microwave measurements, low-temperature measurement techniques, low noise measurements, and common devices used in quantum information. The course will have three modules. The first module, basics of electronic measurements, will include chip layout, power measurements, ground loop testing, impedance measurements, noise fundamentals, cable and device fabrication and care. The second module, high frequency measurements, will include measurements of basic scattering parameters, accuracy enhancement and calibration, transmission line, amplifier, and oscillator characterization including noise measurements. The third module, low-temperature measurements, will cover critical parameters for superconductors and Josephson junctions, measurements of superconducting resonators, characterization of low-temperature electronic elements including amplifiers. At the end of this course the students will know how to use network analyzers, spectrum analyzers, cryostats, the software Eagle for chip design, amplifiers, and filters. Prerequisite: EENG385, PHGN215, or equivalent Electronics Devices & Circuits course.

**EENG536. PHASED & ADAPTIVE ARRAYS. 3.0 Semester Hrs.**
This course introduces the basic fundamentals of phased arrays and adaptive antenna arrays with a focus on array processing. The topics that will be introduced are antenna array fundamentals and radiation analysis techniques, elements for antenna arrays, linear, planar, and non-planar arrays, focused arrays, radiation pattern synthesis, phased array and adaptive array system architectures, phase-delay and time-delay systems, analog and digital beamforming, adaptive nulling algorithms and interference cancellation, and angle of arrival estimation algorithms. This foundational knowledge will then be used by the students to conduct a comprehensive course project on a special topic in this area. Prerequisite: EENG515 or instructor consent. Corequisite: EENG411 or instructor consent.

**EENG540. INTRODUCTION TO RADAR SYSTEMS. 3.0 Semester Hrs.**
(I) This course provides an introduction to radar system engineering, it covers the fundamental concepts needed to understand the design and operation of modern radar systems for a variety of applications. Topics covered include the radar equation, radar cross section, radar clutter, detection and receiver design, transmitters and antenna systems. Applications include pulsed, continuous-wave, and frequency-modulated radars, Doppler radar, and synthetic aperture radar. Demonstrations will be conducted to complement the theoretical analysis. Prerequisite: EENG425 or EENG525. 3 hours lecture; 3 semester hours.

**EENG570. ADVANCED HIGH POWER ELECTRONICS. 3.0 Semester Hrs.**
(I) Basic principles of analysis and design of circuits utilizing high power electronics. AC/DC, DC/AC, AC/AC, and DC/DC conversion techniques. Laboratory project comprising simulation and construction of a power electronics circuit. Prerequisites: EENG470 or consent of instructor. 3 hours lecture; 3 semester hours. Fall semester even years.

**EENG571. MODERN ADJUSTABLE SPEED ELECTRIC DRIVES. 3.0 Semester Hrs.**

(II) An introduction to electric drive systems for advanced applications. The course introduces the treatment of vector control of induction and synchronous motor drives using the concepts of general flux orientation and the feedforward (indirect) and feedback (direct) voltage and current vector control. AC models in space vector complex algebra are also developed. Other types of drives are also covered, such as reluctance, stepper-motor and switched-reluctance drives. Digital computer simulations are used to evaluate such implementations. Pre-requisite: Familiarity with power electronics and power systems, such as covered in EENG470 or consent of instructor. 3 lecture hours; 3 semester hours. Spring semester of even years.

**EENG572. RENEWABLE ENERGY AND DISTRIBUTED GENERATION. 3.0 Semester Hrs.**

A comprehensive electrical engineering approach on the integration of alternative sources of energy. One of the main objectives of this course is to focus on the inter-disciplinary aspects of integration of the alternative sources of energy which will include most common and also promising types of alternative primary energy: hydropower, wind power, photovoltaic, fuel cells and energy storage with the integration to the electric grid. Pre-requisite: It is assumed that students will have some basic and broad knowledge of the principles of electrical machines, thermodynamics, power electronics, direct energy conversion, and fundamentals of electric power systems such as covered in basic engineering courses plus EENG480 and EENG470. 3 lecture hours; 3 semester hours. Fall semester of odd years.

**EENG573. ELECTRIC POWER QUALITY. 3.0 Semester Hrs.**

(II) Electric power quality (PQ) deals with problems exhibited by voltage, current and frequency that typically impact end-users (customers) of an electric power system. This course is designed to familiarize the concepts of voltage sags, harmonics, momentary disruptions, and waveform distortions arising from various sources in the system. A theoretical and mathematical basis for various indices, standards, models, analyses techniques, and good design procedures will be presented. Additionally, sources of power quality problems and some remedies for improvement will be discussed. The course bridges topics between power systems and power electronics. Prerequisite: EENG480 and EENG470 or consent of instructor. 3 lecture hours; 3 semester hours.

**EENG577. ADVANCED ELECTRICAL MACHINE DYNAMICS FOR SMART-GRID SYSTEMS. 3.0 Semester Hrs.**

(I, II, S) This course provides engineering science analysis and focuses on the application of the ?abc? frame of reference to develop state space and equivalent network models for electric machines and drive systems. The course focuses primarily on the modeling and dynamic performance prediction of electric machines and associated power electronic in smart grids and renewable energy systems/subsystems. The developed models will be used in computer simulations for the characterization and performance prediction of synchronous and induction machines, permanent magnet synchronous machines synchronous reluctance and switched reluctance machines, as well as other advanced machine systems, such as axil flux generators and Linear PM machines. 3 hours lecture; 3 semester hours.

**EENG580. POWER DISTRIBUTION SYSTEMS ENGINEERING. 3.0 Semester Hrs.**

(I)This course deals with the theory and applications of problems and solutions as related to electric power distribution systems engineering from both ends: end-users like large industrial plants and electric utility companies. The primary focus of this course in on the medium voltage (4.16 kV ? 69 kV) power systems. Some references will be made to the LV power system. The course includes per-unit methods of calculations; voltage drop and voltage regulation; power factor improvement and shunt compensation; short circuit calculations; theory and fundamentals of symmetrical components; unsymmetrical faults; overhead distribution lines and power cables; basics and fundamentals of distribution protection. Prerequisites: EENG480 or consent of instructor. 3 lecture hours; 3 semester hours. Fall semester of odd years.

**EENG581. POWER SYSTEM OPERATION AND MANAGEMENT. 3.0 Semester Hrs.**

(I) This course presents a comprehensive exposition of the theory, methods, and algorithms for Energy Management Systems (EMS) in the power grid. It will focus on (1) modeling of power systems and generation units, (2) methods for dispatching generating resources, (3) methods for accurately estimating the state of the system, (4) methods for assessing the security of the power system, and (5) an overview of the market operations in the grid. Prerequisite: EENG480. 3 lecture hours; 3 semester hours.

**EENG582. HIGH VOLTAGE AC AND DC POWER TRANSMISSION. 3.0 Semester Hrs.**

(I) This course deals with the theory, modeling and applications of HV and EHV power transmission systems engineering. The primary focus is on overhead AC transmission line and voltage ranges between 115 kV to 500 kV. HVDC and underground transmission will also be discussed. The details include the calculations of line parameters (RLC); steady-state performance evaluation (voltage drop and regulation, losses and efficiency) of short, medium and long lines; reactive power compensation; FACTS devices; insulation coordination; corona; insulators; sag-tension calculations; EMTP, traveling wave and transients; fundamentals of transmission line design; HV and EHV power cables: solid dielectric, oil-filled and gas-filled; Fundamentals of DC transmission systems including converter and filter. Prerequisites: EENG480 or consent of instructor. 3 lecture hours; 3 semester hours. Fall semester of even years.

**EENG583. ADVANCED ELECTRICAL MACHINE DYNAMICS. 3.0 Semester Hrs.**

(II) This course deals primarily with the two rotating AC machines currently utilized in the electric power industry, namely induction and synchronous machines. The course is divided in two halves: the first half is dedicated to induction and synchronous machines are taught in the second half. The details include the development of the theory of operation, equivalent circuit models for both steady-state and transient operations, all aspects of performance evaluation, IEEE methods of testing, and guidelines for industry applications including design and procurement. Prerequisites: EENG480 or consent of instructor. 3 lecture hours; 3 semester hours. Spring semester of even years.

**EENG584. POWER SYSTEM RISK MANAGEMENT. 3.0 Semester Hrs.**

(II) This course presents a comprehensive exposition of the theory, methods, and algorithms for risk management in the power grid. The course will focus on: (1) power system stability analysis (steady state, dynamic, and transient), (2) analysis of internal and external threats to power systems, e.g. component failures, faults, natural hazards, cyber intrusions, (3) introduction to power system security assessment, (4) fundamentals of modeling risk, vulnerability assessment and loss calculations, (5) mitigating techniques before, during and after the course of major events and disturbances. Prerequisites: EENG480, EENG481. 3 hours lecture; 3 semester hours. Years to be Offered: Every Other Year.

**EENG586. COMMUNICATION NETWORKS FOR POWER SYSTEMS. 3.0 Semester Hrs.**

Advanced topics on communication networks for power systems including the fundamentals of communication engineering and signal modulation/transfer, physical layer for data transfer (e.g., wireline, wireless, fiber optics), different communication topologies for power networks (e.g., client-server, peer-to-peer), fundamentals of SCADA system, data modeling and communication services for power system applications, common protocols for utility and substation automation, and cyber-security in power networks. Prerequisites: EENG480. 3 hours of lecture; 3 credit hours. Fall, odd years.

**EENG587. POWER SYSTEMS PROTECTION AND RELAYING. 3.0 Semester Hrs.**

(II) Theory and practice of power system protection and relaying; Study of power system faults and symmetrical components; Fundamental principles and tools for system modeling and analysis pertaining to relaying, and industry practices in the protection of lines, transformers, generators, motors, and industrial power systems; Introduction to microprocessor based relaying, control, and SCADA. Prerequisites: EENG480 or consent of instructor. 3 hours of lecture; 3 credit hours. Spring, odd years.

**EENG588. ENERGY POLICY, RESTRUCTURING AND DEREGULATION OF ELECTRICITY MARKET. 3.0 Semester Hrs.**

The big picture of electric power, electricity and energy industry; Restructuring and Deregulation of electricity market; Energy Policy Acts and its impact on electricity market and pricing; Energy economics and pricing strategy; Public policy issues, reliability and security; Regulation. Prerequisites: EENG389. 3 hours of lecture; 3 credit hours. Fall, odd years.

**EENG589. DESIGN AND CONTROL OF WIND ENERGY SYSTEMS. 3.0 Semester Hrs.**

(II) Wind energy provides a clean, renewable source for electricity generation. Wind turbines provide electricity at or near the cost of traditional fossil-fuel fired power plants at suitable locations, and the wind industry is growing rapidly as a result. Engineering R&D can still help to reduce the cost of energy from wind, improve the reliability of wind turbines and wind farms, and help to improve acceptance of wind energy in the public and political arenas. This course will provide an overview of the design and control of wind energy systems. Offered Spring semester of odd years. 3 hours lecture; 3 semester hours.

**EENG598. SPECIAL TOPICS IN ELECTRICAL ENGINEERING. 6.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**EENG598. SPECIAL TOPICS IN ELECTRICAL ENGINEERING. 6.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**EENG599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**

(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**EENG600. GRADUATE SEMINAR ON SMART-GRID ELECTRICAL POWER AND ENERGY SYSTEMS. 3.0 Semester Hrs.**

(I, II, S) In this course, learners will plan, develop, and present a research project in their field of technology on a subject related to Smart-Grid, Electrical Power, and Energy Systems. Their chosen topic and seminar must demonstrate their knowledge and skills in scientific and engineering analysis and modeling, project handling, technical writing, problem-solving, evaluation and assessment of their goals, and oral presentation techniques. Learners will advance their research training in the design of future electric power grids, conduct analysis, simulation and data evaluation of electricity infrastructure in the area of Smart Cities, prosumers and distributed generation and will attend and make seminar or another modern presentation on cutting-edge issues of enhanced livability, enhanced workability, and increased sustainability for Transportation and Electrification, Power System Resiliency, Energy Economy, Community Micro-grids, Data Analytics, and Renewable Energy. 3 hours lecture; 3 semester hours.

**EENG617. INTELLIGENT CONTROL SYSTEMS. 3.0 Semester Hrs.**

Fundamental issues related to the design on intelligent control systems are described. Neural networks analysis for engi neering systems are presented. Neural-based learning, estimation, and identification of dynamical systems are described. Qualitative control system analysis using fuzzy logic is presented. Fuzzy mathematics design of rule-based control, and integrated human-machine intelligent control systems are covered. Real-life problems from different engineering systems are analyzed. Prerequisite: EENG517. 3 hours lecture; 3 semester hours. Taught on demand.

**EENG618. NONLINEAR AND ADAPTIVE CONTROL. 3.0 Semester Hrs.**

This course presents a comprehensive exposition of the theory of nonlinear dynamical systems and the applications of this theory to adaptive control. It will focus on (1) methods of characterizing and understanding the behavior of systems that can be described by nonlinear ordinary differential equations, (2) methods for designing controllers for such systems, (3) an introduction to the topic of system identification, and (4) study of the primary techniques in adaptive control, including model-reference adaptive control and model predictive control. Prerequisite: EENG517. 3 hours lecture; 3 semester hours. Spring, even numbered years.

**EENG683. COMPUTER METHODS IN ELECTRIC POWER SYSTEMS. 3.0 Semester Hrs.**
This course deals with the computer methods and numerical solution techniques applied to large scale power systems. Primary focus includes load flow, short circuit, voltage stability and transient stability studies and contingency analysis. The details include the modeling of various devices like transformer, transmission lines, FACTS devices, and synchronous machines. Numerical techniques include solving a large set of linear or non-linear algebraic equations, and solving a large set of differential equations. A number of simple case studies (as per IEEE standard models) will be performed. Prerequisites: EENG583, EENG580 and EENG582 or equivalent; a strong knowledge of digital simulation techniques. 3 lecture hours; 3 semester hours. Taught on demand.

**EENG698. SPECIAL TOPICS IN ELECTRICAL ENGINEERING. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**EENG699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**EENG707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

## Professor and Department Head

Peter Aaen

## Professors

Atef Elsherbeni

Randy Haupt

Kevin Moore

P.K. Sen

Marcelo Simoes

Tyrone Vincent

Michael Wakin

## Associate professors

Kathryn Johnson

Salman Mohagheghi

## Assistant professors

Payam Nayeri

Gongguo Tang

## Teaching Professors

Abdul-Rahman Arkadan (Graduate Faculty)

Stephanie Claussen

Vibhuti Dave

Jeff Schowalter

## Teaching Associate Professor

Chris Coulston

## Research Professor

Mohammed Hadi

## Emerita Professor

Catherine Skokan

## Emeritus Professor

Ravel Ammerman

# Geology and Geological Engineering

## Degrees Offered

- Master of Science (Geology)
- Master of Science (Geological Engineering)
- Doctor of Philosophy (Geology)
- Doctor of Philosophy (Geological Engineering)
- Master of Engineering (Geological Engineering) (Non-Thesis)
- Professional Master Degree (Petroleum Reservoir Systems) (Non-Thesis)
- Professional Master Degree (Mineral Exploration) (Non-Thesis)
- Graduate Certificate of Economic Geology
- Graduate Certificate of Exploration Methods

## Program Description

The Department of Geology and Geological Engineering offers Master of Science and Doctor of Philosophy degrees in Geology; and Master of Engineering, and Master of Science and Doctor of Philosophy degrees in Geological Engineering. Professional Master Degrees are offered in Petroleum Reservoir Systems and Mineral Exploration. Geological Engineering degrees require possession or acquisition of an undergraduate engineering degree or its equivalent.

Graduate students desiring to study ground water, engineering geology/geotechnics, mining engineering geology and some environmental applications are generally expected to pursue the Geological Engineering degree. Students desiring to study petroleum or minerals exploration or development sciences, and/or geology generally pursue Geology degrees.

Geoscience students may also choose among several interdisciplinary graduate programs comprised of faculty from several different Mines departments. The most common choices are Geochemistry, Hydrologic Science and Engineering, and Underground Construction and Tunnel Engineering. Please see sections in the Catalog for each of these programs.

## Program Details for Geology Degrees

**The Master of Science (Geology)** program will require 36 semester hours of course and research credit hours (a maximum of 9 credit hours may be 400-level course work). Twelve of the 36 credit hours must be research credits. All Master of Science (Geology) candidates must also complete an appropriate thesis, based upon original research they have conducted. A thesis proposal and course of study must be approved by the student's Thesis Advisory Committee before the candidate begins substantial work on the thesis research.

**The Doctor of Philosophy (Geology)** academic program requires a minimum of 72 hours of course and research credit hours (a maximum of 9 credit hours may be 400-level course work). At least 24 of the hours must be research credit hours and at least 36 must be course credit hours. Students who enter the PhD program with a thesis-based Master's degree may transfer up to 36 semester hours in recognition of the course work and research completed for that degree (up to 24 of these semester hours can come from previous graduate-level course work). The specific courses and total number of hours that may transfer are at the discretion of the student's Doctoral Thesis Advisory Committee. All Doctor of Philosophy (Geology) students must pass a comprehensive examination, which is expected to be conducted immediately following the semester in which the required 36 course credit hours have been completed, and no later than by the end of the second year of their program. This timing may be adjusted for part-time students. This examination will be administered by the student's Doctoral committee and will consist of an oral and a written examination, administered in a format to be determined by the Doctoral Committee. Two negative votes in the Doctoral Committee constitute failure of the examination. Depending on the outcome of the qualifying examination, the Doctoral Thesis Advisory Committee can recommend students to take up to 6 additional course credits. In case of failure of the qualifying examination, a re-examination may be given upon the recommendation of the Doctoral Committee and approval of the Graduate Dean. Only one re-examination may be given. Students must also complete an appropriate thesis based upon original research they have conducted and are encouraged to have submitted at least two manuscripts based on the dissertation work for publication in peer-reviewed scholarly journals before defending their thesis. A thesis proposal and course of study must be approved by the student's Doctoral Thesis Advisory Committee before the student begins substantial work on the thesis research.

**Prerequisites for Geology Degrees**

No specific pre-requisites are required for admission to the Geology Degree program. However, it is highly recommended that the candidates have the following courses prior to application:

- General Geology
- Field camp or equivalent (6 weeks)
- Structural Geology
- Mineralogy
- Petrology
- Stratigraphy
- Chemistry (3 semesters, including at least 1 semester of physical or organic)
- Mathematics (2 semesters of calculus)
- An additional science course (other than geology) or advanced mathematics
- Physics (2 semesters)

The student's committee will reserve the right to request that students complete additional identified courses prior to granting of a degree of **Master of Science (Geology) or Doctor of Philosophy (Geology).**

## Program Details for Geological Engineering Degrees

**The Master of Science (Geological Engineering)** program requires 36 semester hours of course and research credit hours (a maximum of 9 credit hours may be 400-level course work). Twelve of the 36 credit hours must be research credits. The degree includes three areas of specialization: engineering geology/geotechnics, groundwater engineering, and mining geological engineering. All Master of Science (Geological Engineering) candidates must also complete an appropriate thesis, based upon original research they have conducted. A thesis proposal and course of study must be approved by the student's Thesis Advisory Committee before the candidate begins substantial work on the thesis research.

**The Doctor of Philosophy (Geological Engineering)** academic program requires a minimum of 72 hours of course and research credit hours (a maximum of 9 credit hours may be 400-level course work). At least 24 of the hours must be research credit hours.  Students who enter the PhD program with a thesis-based Master's degree may transfer up to 36 semester hours in recognition of the course work and research completed for that degree (up to 24 of these semester hours can come from previous graduate-level course work).   The specific courses and total number of hours that may transfer are at the discretion of the student's Doctoral Thesis Advisory Committee.

All Doctor of Philosophy (Geological Engineering) students must pass a comprehensive examination by the end of the second year of their program.  This timing may be adjusted for part-time students. This examination will be administered by the student's Doctoral committee and will consist of an oral and a written examination, administered in a format to be determined by the Doctoral Committee. Two negative votes in the Doctoral Committee constitute failure of the examination. In case of failure of the qualifying examination, a re-examination may be given upon the recommendation of the Doctoral Committee and approval of the Graduate Dean. Only one re-examination may be given. Students must also complete appropriate thesis based upon original research they have conducted.  A thesis proposal and course of study must be approved by the student's Doctoral Thesis Advisory Committee before the student begins substantial work on the thesis research.

**Core Competencies for Geological Engineering Degrees**
The candidate for the degree of **Master of Science (Geological Engineering) or Doctor of Philosophy (Geological Engineering)** must have completed the following or equivalent subjects prior to graduation. These may be satisfied through previous bachelors-level coursework or during the graduate program. Credit will only be granted for 400-level or graduate-level courses that are equivalent to the titles below.

**Mathematics**

- Calculus (two semesters)
- One semester in two of the following subjects:
    - calculus III
    - differential equations
    - probability and statistics
    - numerical analysis
    - linear algebra
    - operations research
    - optimization

**Basic Science**

- Chemistry (2 semesters)
- Mineralogy and Petrology
- Physics (2 semesters)
- Stratigraphy or Sedimentation
- Physical Geology
- Computer Programming or GIS

**Engineering Science**

- Structural Geology
- Soil Mechanics
- Rock Mechanics
- One semester in two of the following subjects:
    - Physical Chemistry or Thermodynamics
    - Statics
    - Mechanics of Materials
    - Fluid Mechanics
    - Dynamics

**Engineering Design**

- Field Geology
- Engineering Geology
- Hydrogeology

- One semester in three of the following subjects:
    - Foundation Engineering
    - Engineering Hydrology
    - Geomorphology
    - Remote Sensing or GIS
    - Introductory Geophysics
    - Engineering Geology Design
    - Groundwater Engineering Design
    - Other engineering design courses as approved by the program committee

## Program Requirements for Geological Engineering Degrees

In addition to the core competency requirements, the **Master of Science or Doctor of Philosophy degrees with specialization in Engineering Geology/Geotechnics** require:

| | | |
|---|---|---|
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| Candidates must also take at least three of the following: | | |
| GEGN563 | APPLIED NUMERICAL MODELLING FOR GEOMECHANICS | 3.0 |
| GEGN570 | CASE HISTORIES IN GEOLOGICAL ENGINEERING AND HYDROGEOLOGY | 3.0 |
| or GEGN673 | ADVANCED GEOLOGICAL ENGINEERING DESIGN | |
| GEGN573 | GEOLOGICAL ENGINEERING SITE INVESTIGATION | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| or GEGN580 | APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEOSCIENCES | |
| GEGN671 | LANDSLIDES: INVESTIGATION, ANALYSIS & MITIGATION | 3.0 |

Typically, the additional courses are selected from the following topical areas: engineering geology, groundwater engineering, groundwater modeling, soil mechanics and foundations, rock mechanics, underground construction, seismic hazards, geomorphology, geographic information systems, construction management, finite element modeling, waste management, environmental engineering, environmental law, engineering management, and computer programming.

## Program Details for Non-Thesis Masters of Engineering Degrees

**The Master of Engineering (Non-Thesis) Program in Geological Engineering** outlined below may be completed by individuals already holding undergraduate or advanced degrees or as a **combined undergraduate/graduate degree program** by individuals already matriculated as undergraduate students at The Colorado School of Mines. The program is comprised of 24 hours of coursework and 6 hours of independent study (non-thesis project) for a total of 30 semester hours. Prerequisite requirements are the same as those listed for Geological Engineering degrees.

## Mines’ Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines’ Combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their Master of Engineering (Non-Thesis) Program in Geological Engineering. Courses that count towards the graduate degree requirements are defined below and may be used for the purposes of double counting at the discretion of the advisor (ME Non-Thesis). These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit.

Up to nine credit hours can be at the 400 level and the remainder will be 500 or 600 level. For the combined degree program, courses recommended as appropriate for double counting may be chosen from:

| | | |
|---|---|---|
| GEGN403 | MINERAL EXPLORATION DESIGN | 3.0 |
| GEGN439 | PETROLEUM EXPLORATION DESIGN | 3.0 |
| GEGN469 | ENGINEERING GEOLOGY DESIGN | 3.0 |
| GEGN470 | GROUND-WATER ENGINEERING DESIGN | 3.0 |

The typical program plan includes 12 course credit hours in both the fall and the spring terms followed by 6 independent study credit hours during the summer term.

GEGN599 requires a project and report that demonstrate competence in the application of geological engineering principles that merits a grade of B or better. The project topic and content of the report is determined by the student’s advisor, in consultation with the student. The format of the report will follow the guidelines for a professional journal paper.

The student, in consultation with the advisor, must prepare a formal program of courses and independent study topic for approval by the Geological Engineering Graduate Program Committee. The program must be submitted to the committee on or before the end of the first week of classes of the first semester.

The most common difficulty in scheduling completion of the degree involves satisfaction of prerequisites. Common deficiency courses are Statics, Mechanics of Materials, and Fluid Mechanics. These are essential to the engineering underpinnings of the degree. Some students may choose to take these prerequisites elsewhere before arriving on the Mines campus.

The **Masters of Engineering (non-thesis)** requires the following courses in addition to the prerequisites:

| | | |
|---|---|---|
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| GEGN599 | INDEPENDENT STUDY | 6.0 |
| Candidates must also take at least three of the following: | | |
| GEGN563 | APPLIED NUMERICAL MODELLING FOR GEOMECHANICS | 3.0 |
| GEGN570 | CASE HISTORIES IN GEOLOGICAL ENGINEERING AND HYDROGEOLOGY | 3.0 |
| or GEGN673 | ADVANCED GEOLOGICAL ENGINEERING DESIGN | |
| GEGN573 | GEOLOGICAL ENGINEERING SITE INVESTIGATION | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| or GEGN580 | APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEOSCIENCES | |
| GEGN671 | LANDSLIDES: INVESTIGATION, ANALYSIS & MITIGATION | 3.0 |

Electives and course substitutions are approved by the advisor. Possibilities for other electives include graduate- level rock mechanics and rock engineering, soil mechanics and foundations, ground water, site characterization, geographical information systems (GIS), project management and geophysics, for example.

## Program Details for Professional Master Degrees

Candidates for the Professional Master Degree must possess an appropriate geosciences undergraduate degree or its equivalent. Prerequisites are the same as those required for the Master of Science (Geology) Degree.

## Professional Master in Mineral Exploration

This non-thesis, master degree program is designed for working professionals who want to increase their knowledge and skills, while gaining a thorough up-date of advances across the spectrum of economic geology, mineral exploration techniques, and mining geosciences. Admission to the program is competitive. Preference will be given to applicants with a minimum of two years of industrial or equivalent experience.

The program requires a minimum of 30 credit hours of coursework, and no research is required. A minimum of 15 credit hours must be accumulated in five of the following core areas:

- mineral deposits,
- mineral exploration,
- applied geophysics,
- applied geochemistry,
- applied structural geology,
- petrology,
- field geology, and
- economic evaluation.

An additional 15 credit hours may be selected from the course offerings of the Department of Geology and Geological Engineering and allied departments including Mining Engineering, Economics and Business, Geophysics, Chemistry and Geochemistry, Metallurgy and Materials Science, and Environmental Sciences.

Selection of courses will be undertaken in consultation with the academic advisor. Up to 9 credit hours may be at the 400-level. All other credits towards the degree must be 500-level or above. A maximum of 9 credit hours may be independent study focusing on a topic relevant to the mineral exploration and mining industries.

## Mines Combined Undergraduate / Graduate Program

Students enrolled in Mine's Combined Undergraduate/Graduate Program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any courses that count towards the graduate degree requirements as either "Required Coursework" or "Elective Coursework", as defined below, may be used for the purposes of double counting at the discretion of the advisor (MS Non-Thesis). These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit.

## Professional Masters in Petroleum Reservoir Systems

The Professional Masters in Petroleum Reservoir Systems (PMPRS) degree is designed for individuals who have petroleum industry experience and are interested in increasing their knowledge across the disciplines of geology, geophysics, and petroleum engineering. This is an interdisciplinary, non-thesis master's degree for students interested in working as geoscience professionals in the petroleum industry. Details including program requirements and description can be found on the Interdisciplinary section of the catalog or by searching for Petroleum Reservoir Systems.

## Program Details for Graduate Certificates

## Certificate and Degree Requirements

We offer two graduate certificates and a Professional Master's degree (non-thesis). The courses taken for certificate degrees can be used towards the Professional Master's degree.

The Graduate Certificate Programs in Economic Geology and Exploration Methods outlined below may be completed by individuals already holding undergraduate or advanced degree in geology or a related field and have at least 2-3 years of professional experience. The programs are comprised of:

| | |
|---|---|
| Course Work | 12.0 Hours |
| Total Semester Hrs | 12.0 Hours |

Up to 3.0 credit hours can be at the 400-level and the remainder will be 500- or 600-level as listed below.

## Graduate Certificate of Economic Geology

Students working towards a Graduate Certificate of Economic Geology are required to take at least 6.0 credits out of the following courses, courses cannot be used in fulfilling the requirements of other Certificates:

**Core courses:**

| | | |
|---|---|---|
| GEOL513 | HYDROTHERMAL GEOCHEMISTRY | 3.0 |
| GEOL521 | FIELD AND ORE DEPOSIT GEOLOGY | 3.0 |
| GEOL524 | ECONOMIC GEOLOGY | 3.0 |
| GEOL598 | SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING (Skarns and Related Deposits) | 3.0 |

Students working towards a Graduate Certificate of Economic Geology can choose up to 6.0 credits out of the following courses, courses cannot be used in fulfilling the requirements of other Certificates:

**Electives:**

| | | |
|---|---|---|
| GEOL505 | ADVANCED STRUCTURAL GEOLOGY | 3.0 |
| GEOL519 | ABITIBI GEOLOGY AND EXPLORATION FIELD SCHOOL | 3.0 |
| GEOL520 | NEW DEVELOPMENTS IN THE GEOLOGY AND EXPLORATION OF ORE DEPOSITS | 2.0 |
| GEOL523 | REFLECTED LIGHT AND ELECTRON MICROSCOPY | 2.0 |
| GEOL525 | PRINCIPLES OF METAMORPHIC GEOLOGY | 3.0 |
| GEGN530 | CLAY CHARACTERIZATION | 2.0 |
| GEOL540 | ISOTOPE GEOCHEMISTRY AND GEOCHRONOLOGY | 3.0 |
| GEOL555 | STRUCTURAL FIELD RESEARCH | 4.0 |
| GEOL601 | CORE TO OUTCROP STRATIGRAPHY | 2.0 |
| GEOL628 | ADVANCED IGNEOUS PETROLOGY | 3.0 |
| GEOL645 | VOLCANOLOGY | 3.0 |
| CHGC503 | INTRODUCTION TO GEOCHEMISTRY | 3.0 |

## Graduate Certificate of Exploration Methods

Students working towards a Graduate Certificate of Economic Geology are required to take at least 6.0 credits out of the following courses, courses cannot be used in fulfilling the requirements of other Certificates:

**Core courses:**

| | | |
|---|---|---|
| GEGX571 | GEOCHEMICAL EXPLORATION | 3.0 |
| GEOL519 | ABITIBI GEOLOGY AND EXPLORATION FIELD SCHOOL | 3.0 |
| GEOL520 | NEW DEVELOPMENTS IN THE GEOLOGY AND EXPLORATION OF ORE DEPOSITS | 2.0 |
| GEOL523 | REFLECTED LIGHT AND ELECTRON MICROSCOPY | 2.0 |
| GPGN598 | GEOPHYSICS FOR MINERAL EXPLORATION | 3.0 |

Students working towards a Graduate Certificate of Economic Geology can choose up to 6.0 credits out of the following courses, courses cannot be used in fulfilling the requirements of other Certificates:

**Electives:**

| | | |
|---|---|---|
| GEGN401 | MINERAL DEPOSITS | 4.0 |
| GEGN403 | MINERAL EXPLORATION DESIGN | 3.0 |
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEGN588 | ADVANCED GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEOL501 | APPLIED STRATIGRAPHY | 4.0 |
| GEOL514 | BUSINESS OF ECONOMIC GEOLOGY | 3.0 |
| GEOL521 | FIELD AND ORE DEPOSIT GEOLOGY | 3.0 |
| GEOL524 | ECONOMIC GEOLOGY | 3.0 |
| GEOL555 | STRUCTURAL FIELD RESEARCH | 4.0 |

| | | |
|---|---|---|
| GEOL598 | SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING (Skarns and Related Deposits) | 3.0 |
| GEOL601 | CORE TO OUTCROP STRATIGRAPHY | 2.0 |
| GPGN411 | GRAVITY AND MAGNETIC METHODS | 3.0 |
| GPGN420 | ELECTRICAL AND ELECTROMAGNETIC METHODS | 3.0 |
| GPGN461 | SEISMIC DATA PROCESSING | 4.0 |
| MNGN427 | MINE VALUATION | 2.0 |
| MNGN438 | GEOSTATISTICS | 3.0 |
| MNGN510 | FUNDAMENTALS OF MINING AND MINERAL RESOURCE DEVELOPMENT | 3.0 |
| MNGN528 | MINING GEOLOGY | 3.0 |
| CHGC504 | METHODS IN GEOCHEMISTRY | 3.0 |

## Professional Master in Mineral Exploration

Candidates for the degree must possess an appropriate geosciences undergraduate degree or its equivalent. Prerequisites are the same as those required for the Master of Science (Geology) Degree.

This non-thesis, master degree program is designed for working professionals who want to increase their knowledge and skills, while gaining a thorough up-date of advances across the spectrum of economic geology, mineral exploration techniques, and mining geosciences. Admission to the program is competitive. Preference will be given to applicants with a minimum of two years of industrial or equivalent experience.

The program requires a minimum of 30 credit hours of coursework, and no research is required. A minimum of 15 credit hours must be accumulated in five of the following core areas:

- mineral deposits,
- mineral exploration,
- applied geophysics,
- applied geochemistry,
- applied structural geology,
- petrology,
- field geology, and
- economic evaluation.

An additional 15 credit hours may be selected from the course offerings of the Department of Geology and Geological Engineering and allied departments including Mining Engineering, Economics and Business, Geophysics, Chemistry and Geochemistry, Metallurgy and Materials Science, and Environmental Sciences.

Selection of courses will be undertaken in consultation with the academic advisor. Up to 9 credit hours may be at the 400-level. All other credits towards the degree must be 500-level or above. A maximum of 9 credit hours may be independent study focusing on a topic relevant to the mineral exploration and mining industries.

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## Courses

**GEGN503. INTEGRATED EXPLORATION AND DEVELOPMENT. 3.0 Semester Hrs.**
(I) Students work alone and in teams to study reservoirs from fluvial-deltaic and valley fill depositional environments. This is a multidisciplinary course that shows students how to characterize and model subsurface reservoir performance by integrating data, methods and concepts from geology, geophysics and petroleum engineering. Activities include field trips, computer modeling, written exercises and oral team presentations. Prerequisite: none. 2 hours lecture, 3 hours lab; 3 semester hours. Offered fall semester, odd years.

**GEGN504. INTEGRATED EXPLORATION AND DEVELOPMENT. 3.0 Semester Hrs.**
(I) Students work in multidisciplinary teams to study practical problems and case studies in integrated subsurface exploration and development. The course addresses emerging technologies and timely topics with a general focus on carbonate reservoirs. Activities include field trips, 3D computer modeling, written exercises and oral team presentation. Prerequisite: none. 3 hours lecture and seminar; 3 semester hours. Offered fall semester, even years.

**GEGN509. INTRODUCTION TO AQUEOUS GEOCHEMISTRY. 3.0 Semester Hrs.**
(I) Analytical, graphical and interpretive methods applied to aqueous systems. Thermodynamic properties of water and aqueous solutions. Calculations and graphical expression of acid-base, redox and solution-mineral equilibria. Effect of temperature and kinetics on natural aqueous systems. Adsorption and ion exchange equilibria between clays and oxide phases. Behavior of trace elements and complexation in aqueous systems. Application of organic geochemistry to natural aqueous systems. Light stable and unstable isotopic studies applied to aqueous systems. Prerequisite: DCGN209 or equivalent. 3 hours lecture; 3 semester hours.

**GEGN520. INDUSTRIAL MINERALS AND ROCKS. 3.0 Semester Hrs.**
Introduction to the Industrial Minerals industry via appreciation of geologic occurrence, physical and chemical material properties, mining and processing considerations, and marketing of various commodities. Development of skills in preparation of commodity surveys, reserves and resources classifications, and project appraisals. Required field trips to operational sites and trip reports. Mid-term and final exams. Individual student commodity term project and presentation. Prerequisite: Senior or graduate status in earth resources field. 3 hours lecture/seminar; 3 semester hours. Offered alternate years when student demand is sufficient.

**GEGN527. ORGANIC GEOCHEMISTRY OF FOSSIL FUELS AND ORE DEPOSITS. 3.0 Semester Hrs.**

(II) A study of organic carbonaceous materials in relation to the genesis and modification of fossil fuel and ore deposits. The biological origin of the organic matter will be discussed with emphasis on contributions of microorganisms to the nature of these deposits. Biochemical and thermal changes which convert the organic compounds into petroleum, oil shale, tar sand, coal, and other carbonaceous matter will be studied. Principal analytical techniques used for the characterization of organic matter in the geosphere and for evaluation of oil and gas source potential will be discussed. Laboratory exercises will emphasize source rock evaluation, and oil-source rock and oil-oil correlation methods. Prerequisite: CHGN221, GEGN438. 2 hours lecture; 3 hours lab; 3 semester hours. Offered alternate years.

**GEGN528. MINING GEOLOGY. 3.0 Semester Hrs.**

Role of geology and the geologist in the development and production stages of a mining operation. Topics addressed: mining operation sequence, mine mapping, drilling, sampling, reserve estimation, economic evaluation, permitting, support functions. Field trips, mine mapping, data evaluation, exercises and term project. Prerequisite: GEGN401 or GEGN405.

**GEGN530. CLAY CHARACTERIZATION. 2.0 Semester Hrs.**

Equivalent with GEOL530,

(I) Clay mineral structure, chemistry and classification, physical properties (flocculation and swelling, cation exchange capacity, surface area and charge), geological occurrence, controls on their stabilities. Principles of X-ray diffraction, including sample preparation techniques, data collection and interpretation, and clay separation and treatment methods. The use of scanning electron microscopy to investigate clay distribution and morphology. Methods of measuring cation exchange capacity and surface area. Prerequisites: GEGN206. 1 hour lecture, 3 hours lab; 2 semester hours.

**GEGN532. GEOLOGICAL DATA ANALYSIS. 3.0 Semester Hrs.**

(II) Techniques and strategy of data analysis in geology and geological engineering: basic statistics review, mapping, sampling and sample representativity, univariate and multivariate statistics, regression, hypothesis testing, cluster and discriminant analysis, principal component analysis, geostatistics. Practical experience in learning to write code in Matlab and use of data sets from case histories. 3 hours lecture; 3 semester hours. Prerequisite: MATH201 or MATH530.

**GEGN542. ADVANCED DIGITAL TERRAIN ANALYSIS. 3.0 Semester Hrs.**

Application of GIS and Remote Sensing principles to solve geoscience and geological engineering problems, with an emphasis on modeling and visualizing the surface of the Earth, performing analysis and support decision making for a variety of applications. Course will present in-depth analysis of specific digital terrain analysis techniques, followed by application exercises. Topics will include analysis and hazard studies of erosion, landslides, stream restoration, wildfire, and environmental issues.

**GEGN561. UNDERGROUND CONSTRUCTION ENGINEERING LABORATORY 1. 0.5 Semester Hrs.**

(I) This course provides students with hands-on experience with tools and skills which are commonly used in the underground construction industry. Bi-weekly labs integrate with other courses in the field of Underground Construction and Tunnel Engineering. Co-requisites: CEEN513. 1.5 hours lab; 0.5 semester hours.

**GEGN562. UNDERGROUND CONSTRUCTION ENGINEERING LABORATORY 2. 0.5 Semester Hrs.**

(II) This course provides students with hands-on experience with tools and skills which are commonly used in the underground construction industry. Bi-weekly labs integrate with other courses in the field of Underground Construction and Tunnel Engineering. Co-requisites: MNGN504 or CEEN523. 1.5 hours lab; 0.5 hours.

**GEGN563. APPLIED NUMERICAL MODELLING FOR GEOMECHANICS. 3.0 Semester Hrs.**

(I) Course focuses on a comprehensive suite of numerical analysis techniques suited to geotechnical design with a focus on excavations in rock/soil and landslides. Finite element, finite difference, discrete/distinct element and boundary element methods are all discussed with hands-on application workshops using state-of-the-art geomechanics software. Analytical models and pre- and post- processing techniques suited to typical rock engineering problems are developed through assignments. Strength criteria and non-linear inelastic constitutive models for continuum plasticity, brittle fracture and discontinuum deformation are explored in detail. Projects involving real case histories are undertaken to highlight the application of and engineering judgment associated with numerical analysis for problems involving rockmasses. Prerequisites: GEGN468, MNGN321 or CEEN312. 3 hours lecture; 3 semester hours.

**GEGN570. CASE HISTORIES IN GEOLOGICAL ENGINEERING AND HYDROGEOLOGY. 3.0 Semester Hrs.**

(I) Case histories in geological and geotechnical engineering, ground water, and waste management problems. Students are assigned problems and must recommend solutions and/or prepare defendable work plans. Discussions center on the role of the geological engineer in working with government regulators, private-sector clients, other consultants, and other special interest groups. Prerequisite: GEGN467, GEGN468, GEGN469, GEGN470. 3 hours lecture; 3 semester hours.

**GEGN571. ADVANCED ENGINEERING GEOLOGY. 3.0 Semester Hrs.**

(I) Emphasis will be on engineering geology mapping methods, and geologic hazards assessment applied to site selection and site assessment for a variety of human activities. Prerequisite: GEGN468 or equivalent. 2 hours lecture, 3 hours lab; 3 semester hours. Offered alternate years.

**GEGN573. GEOLOGICAL ENGINEERING SITE INVESTIGATION. 3.0 Semester Hrs.**

(I) Methods of field investigation, testing, and monitoring for geotechnical and hazardous waste sites, including: drilling and sampling methods, sample logging, field testing methods, instrumentation, trench logging, foundation inspection, engineering stratigraphic column and engineering soils map construction. Projects will include technical writing for investigations (reports, memos, proposals, workplans). Class will culminate in practice conducting simulated investigations (using a computer simulator). 3 hours lecture; 3 semester hours.

**GEGN575. APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS. 3.0 Semester Hrs.**

(II) An introduction to Geographic Information Systems (GIS) and their applications to all areas of geology and geological engineering. Lecture topics include: principles of GIS, data structures, digital elevation models, data input and verification, data analysis and spatial modeling, data quality and error propagation, methods of GIS evaluation and selection. Laboratories will use Macintosh and DOS-based personal computer systems for GIS projects, as well as video-presentations. Visits to local GIS laboratories, and field studies will be required. 2 hours lecture, 3 hours lab; 3 semester hours.

**GEGN578. GIS PROJECT DESIGN. 1-3 Semester Hr.**

(I, II) Project implementation of GIS analysis. Projects may be undertaken by individual students, or small student teams. Documentation of all project design stages, including user needs assessment, implementation procedures, hardware and software selection, data sources and acquisition, and project success assessment. Various GIS software may be used; projects may involve 2-dimensional GIS, 3-dimensional subsurface models, or multi-dimensional time-series analysis. Prerequisite: none. Variable credit, 1-3 semester hours, depending on project. Offered on demand.

**GEGN579. PYTHON SCRIPTING FOR GEOGRAPHIC INFORMATION SYSTEMS. 3.0 Semester Hrs.**

(I) Students will learn to use Python scripting with ArcGIS to perform common GIS tasks and to develop their own standalone Python scripts for GIS-based problem solving, automating repetitive or complex geoprocessing work flows, and preparing GIS-based maps. Specific topics include: (1) using Python for basic GIS tasks including field manipulation (e.g. adding, deleting, joining, or calculating fields), file manipulation (e.g., creating, deleting, moving, renaming files), and performing basic spatial analyses; (2) creating stand-alone Python scripts and tools; (3) Using the Python mapping module to control map elements in map layouts; and (4) problem solving to explore more advanced features of Python with ArcGIS. Prerequisite: EDNS264. 2 hours lecture, 3 hours lab; 3 semester hours.

**GEGN580. APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEOSCIENCES. 3.0 Semester Hrs.**

(I) This course offers an introduction to remote sensing in general and radar remote sensing and optical remote sensing in specific as well as their applications to all areas of geoengineering and geosicences. Lecture topics include: principles SAR (Synthetic Aperture Radar) and InSAR (Interferometry of Synthetic Aperture Radar) and their applications, as well as basic concepts of optical remote sensing and its application in geoengineering and geosciences. Topics include various sensors and platforms of SAR data acquisition, SAR data access, SAR data processing, data acquisition and processing of optical remote sensing images. Prerequisites: Graduate standing. 2 hours lecture, 3 hours lab, 3 semester hours.

**GEGN581. ANALYTICAL HYDROLOGY. 3.0 Semester Hrs.**

Equivalent with GEGN481,

(I) Introduction to the theory, and hydrological application of, probability, statistics, linear algebra, differential equations, numerical analysis, and integral transforms. The course will require more challenging assignments and exams commensurate with graduate credit. Prerequisites: GEGN467. 3 hours lecture; 3 semester hours.

**GEGN582. INTEGRATED SURFACE WATER HYDROLOGY. 3.0 Semester Hrs.**

(I) This course provides a quantitative, integrated view of the hydrologic cycle. The movement and behavior of water in the atmosphere (including boundary layer dynamics and precipitation mechanisms), fluxes of water between the atmosphere and land surface (including evaporation, transpiration, precipitation, interception and through fall) and connections between the water and energy balances (including radiation and temperature) are discussed at a range of spatial and temporal scales. Additionally, movement of water along the land surface (overland flow and snow dynamics) and in the subsurface (saturated and unsaturated flow) as well as surface-subsurface exchanges and runoff generation are also covered. Finally, integration and connections within the hydrologic cycle and scaling of river systems are discussed. Prerequisites: Groundwater Engineering (GEGN466/GEGN467), Fluid Mechanics (GEGN351/ EGGN351), math up to differential equations, or equivalent classes. 3 hours lecture; 3 semester hours.

**GEGN583. MATHEMATICAL MODELING OF GROUNDWATER SYSTEMS. 3.0 Semester Hrs.**

(II) Lectures, assigned readings, and direct computer experience concerning the fundamentals and applications of finite-difference and finite-element numerical methods and analytical solutions to ground water flow and mass transport problems. Prerequisite: A knowledge of FORTRAN programming, mathematics through differential and integral calculus, and GEGN467. 3 hours lecture; 3 semester hours.

**GEGN584. FIELD METHODS IN HYDROLOGY. 3.0 Semester Hrs.**

(I) Design and implementation of tests that characterize surface and subsurface hydrologic systems, including data logger programming, sensor calibration, pumping tests, slug tests, infiltration tests, stream gauging and dilution measurements, and geophysical (EM, resistivity, and/or SP) surveys. Prerequisites: Groundwater Engineering (GEGN466/ GEGN467, Surface Water Hydrology (ESGN582) or equivalent classes. 2 hours lecture; 5 hours lab and field exercises one day of the week. Days TBD by instructor; 3 semester hours.

**GEGN585. FLUID MECHANICS FOR HYDROLOGY. 2.0 Semester Hrs.**

(I) This class focuses on the fundamental concepts of engineering fluid mechanics as they relate to the study of hydrology. Topics include fluid statics, dynamics, continuity, energy and momentum, dimensional analysis and open channel flow. 2 hours lecture; 2 semester hours.

**GEGN586. NUMERICAL MODELING OF GEOCHEMICAL SYSTEMS. 3.0 Semester Hrs.**

(II) This course provides quantitative methods for evaluating the geochemical characteristics of geological systems. The course is project based with lectures to provide information about the topic and use of geochemical modeling software. Student projects consist of chemical speciation of waters, activity diagrams, reaction progress models, water-rock interactions, sorption and surface complexation, and kinetic mineral reactions. Students complete an individual project on the geochemical system of their choice and present it to the class. Prerequisite: CEEN550 or CHGC509. 3 hours lecture, 3 semester hours. Offered spring semester, odd years.

**GEGN587. HYDROGEOCHEMICAL PROCESSES. 3.0 Semester Hrs.**

(II) Analysis of the chemistry of natural waters in the context of hydrologic systems. The course focuses on sources and dynamic behavior of common natural and anthropogenically introduced solutes of interest, their interactions with minerals, and fate and transport in subsurface and surface environments. 3 hours lecture; 3 semester hours. Co-requisite: None.

**GEGN588. ADVANCED GEOGRAPHIC INFORMATION SYSTEMS. 3.0 Semester Hrs.**

(I, II, S) This course offers spatial statistical methods in modeling and understanding the processes operating in spatial and temporal domains. The visualization (2D and 3D), exploration and modeling for discrete and continuous point data and aerial data are covered. Uni-variate and multivariate geospatial data analyses techniques are explained with their implementation for the selected case studies. Prerequisite: ENDS264 and GEGN432. 3 hours lecture; 3 semester hours.

**GEGN598. SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING. 6.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**GEGN599. INDEPENDENT STUDY IN ENGINEERING GEOLOGY OR ENGINEERING HYDROGEOLOGY. 0.5-6 Semester Hr.**

(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**GEGN669. ADVANCED TOPICS IN ENGINEERING HYDROGEOLOGY. 1-2 Semester Hr.**

(I, II) Review of current literature and research regarding selected topics in hydrogeology. Group discussion and individual participation. Guest speakers and field trips may be incorporated into the course. Prerequisite: none. 1 to 2 semester hours; may be repeated for credit.

**GEGN670. ADVANCED TOPICS IN GEOLOGICAL ENGINEERING. 3.0 Semester Hrs.**

(I, II) Review of current literature and research regarding selected topics in engineering geology. Group discussion and individual participation. Guest speakers and field trips may be incorporated into the course. Prerequisite: none. 3 hours lecture; 3 semester hours. Repeatable for credit under different topics.

**GEGN671. LANDSLIDES: INVESTIGATION, ANALYSIS & MITIGATION. 3.0 Semester Hrs.**

(I) Geological investigation, analysis, and design of natural rock and soil slopes and mitigation of unstable slopes. Topics include landslide types and processes, triggering mechanisms, mechanics of movements, landslide investigation and characterization, monitoring and instrumentation, soil slope stability analysis, rock slope stability analysis, rock fall analysis, stabilization and risk reduction measures. 3 hours lecture; 3 semester hours. Prerequisite: GEGN468, EGGN361, MNGN321, (or equivalents).

**GEGN672. ADVANCED GEOTECHNICS. 3.0 Semester Hrs.**

Practical analysis and application of techniques in weak rock engineering, ground-water control in construction, fluvial stabilization and control, earthquake hazard assessment, engineering geology in construction, engineering geology in dam investigation, and other current topics in geotechnics practice. Prerequisite: GEGN468, CEEN312, CEEN312L and MNGN321. 3 hours lecture; 3 semester hours. Offered alternate years.

**GEGN673. ADVANCED GEOLOGICAL ENGINEERING DESIGN. 3.0 Semester Hrs.**

(II) Application of geological principles and analytical techniques to solve complex engineering problems related to geology, such as mitigation of natural hazards, stabilization of earth materials, and optimization of construction options. Design tools to be covered will include problem solving techniques, optimization, reliability, maintainability, and economic analysis. Students will complete independent and group design projects, as well as a case analysis of a design failure. 3 hours lecture; 3 semester hours. Offered alternate years.

**GEGN681. VADOSE ZONE HYDROLOGY. 3.0 Semester Hrs.**

(II) Study of the physics of unsaturated groundwater flow and contaminant transport. Fundamental processes and data collection methods will be presented. The emphasis will be on analytic solutions to the unsaturated flow equations and analysis of field data. Application to non-miscible fluids, such as gasoline, will be made. The fate of leaks from underground tanks will be analyzed. Prerequisites: GEGN467 or equivalent; Math through Differential Equations. 3 hours lecture; 3 semester hours.

**GEGN682. FLOW AND TRANSPORT IN FRACTURED ROCK. 3.0 Semester Hrs.**

(I) Explores the application of hydrologic and engineering principles to flow and transport in fractured rock. Emphasis is on analysis of field data and the differences between flow and transport in porous media and fractured rock. Teams work together throughout the semester to solve problems using field data, collect and analyze field data, and do independent research in flow and transport in fractured rock. 3 hours lecture; 3 credit hours. Prerequisite: GEGN581.

**GEGN683. ADVANCED GROUND WATER MODELING. 3.0 Semester Hrs.**

(II) Flow and solute transport modeling including: 1) advanced analytical modeling methods; 2) finite elements, random-walk, and method of characteristics numerical methods; 3) discussion of alternative computer codes for modeling and presentation of the essential features of a number of codes; 4) study of selection of appropriate computer codes for specific modeling problems; 5) application of models to ground water problems; and 6) study of completed modeling projects through literature review, reading and discussion. Prerequisite: GEGN509/CHGC509 or GEGN583. 2 hours lecture, 3 hours lab; 3 semester hours.

**GEGN698. SPECIAL TOPICS. 6.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**GEGN699. INDEPENDENT STUDY IN ENGINEERING GEOLOGY OR ENGINEERING HYDROGEOLOGY. 0.5-6 Semester Hr.**

(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**GEGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

**GEGX571. GEOCHEMICAL EXPLORATION. 3.0 Semester Hrs.**
(II) Dispersion of trace metals from mineral deposits and their discovery. Laboratory consists of analysis and statistical interpretation of data of soils, stream sediments, vegetation, and rock in connection with field problems. Term report required. 2 hours lecture, 3 hours lab; 3 semester hours. Prerequisite: none.

**GEOL501. APPLIED STRATIGRAPHY. 4.0 Semester Hrs.**
(I) Review of basic concepts in siliciclastic and carbonate sedimentology and stratigraphy. Introduction to advanced concepts and their application to exploration and development of fossil fuels and stratiform mineral deposits. Modern facies models and sequence-stratigraphic concepts applied to solving stratigraphic problems in field and subsurface settings. Prerequisites: GEOL314 or equivalent. 3 hours lecture, 4 hours lab; 4 semester hours.

**GEOL502. STRUCTURAL METHODS FOR SEISMIC INTERPRETATION. 3.0 Semester Hrs.**
(I) A practical course that covers the wide variety of structural methods and techniques that are essential to produce a valid and coherent interpretation of 2D and 3D seismic reflection data in structurally complex areas. Topics covered include: Extensional tectonics, fold and thrust belts, salt tectonics, inversion tectonics and strike-slip fault systems. Laboratory exercises are based on seismic datasets from a wide variety of structural regimes from across the globe. The course includes a 4 day field trip to SE Utah. Prerequisite: GEOL309 and GEOL314 or GEOL315, or equivalents. 3 hours lecture/lab; 3 semester hours.

**GEOL503. INTEGRATED GEOLOGICAL INTERPRETATION OF 3D SEISMIC DATA. 3.0 Semester Hrs.**
(II) INTEGRATED GEOLOGICAL INTERPRETATION OF 3D SEISMIC DATA-A PRACTICAL COURSE IN SEISMIC INTERPRETATION OF GLOBAL DATASETS. A practical course in workstation based, integrated geological interpretation of 3D seismic reflection data. Course builds directly on the seismic interpretation skills learnt in the prerequisite GEOL502 Structural Methods for Seismic Interpretation. Key concepts developed in this course are: making internally consistent interpretations of complex 3D datasets and developing integrated geological (structural and stratigraphic) interpretations of 3D seismic data. Prerequisite: GEOL502. 3 hours lecture/lab; 3 semester hours.

**GEOL505. ADVANCED STRUCTURAL GEOLOGY. 3.0 Semester Hrs.**
(I) Advanced Structural Geology builds on basic undergraduate Structural Geology. Structures such as folds, faults, foliations, lineations and shear zones will be considered in detail. The course focuses on microstructures, complex geometries and multiple generations of deformation. The laboratory consists of microscopy, in-class problems, and some field-based problems. Prerequisites: GEGN307, GEOL309, GEGN316, GEOL321, or equivalents. 2 hours lecture, 2 hours lab, and field exercise; 3 semester hours.

**GEOL512. MINERALOGY AND CRYSTAL CHEMISTRY. 3.0 Semester Hrs.**
(I) Relationships among mineral chemistry, structure, crystallography, and physical properties. Systematic treatments of structural representation, defects, mineral stability and phase transitions, solid solutions, substitution mechanisms, and advanced methods of mineral identification and characterization. Applications of principles using petrological and environmental examples. Prerequisites: GEOL321, DCGN209 or equivalent. 2 hours lecture, 3 hours lab; 3 semester hours. Offered alternate years.

**GEOL513. HYDROTHERMAL GEOCHEMISTRY. 3.0 Semester Hrs.**
Equivalent with CHGC513,
(II) Geochemistry of high-temperature aqueous systems. Examines fundamental phase relationships in model systems at elevated temperatures and pressures. Major and trace element behavior during fluid-rock interaction. Theory and application of stable isotopes as applied to hydrothermal mineral deposits. Review of the origin of hydrothermal fluids and mechanisms of transport and deposition of ore minerals. Includes the study of the geochemistry of magmatic aqueous systems, geothermal systems, and submarine hydrothermal vents. Prerequisites: GEGN401. 2 hours lecture, 3 hours lab; 3 semester hours.

**GEOL514. BUSINESS OF ECONOMIC GEOLOGY. 3.0 Semester Hrs.**
Examines the business side of mineral exploration including company structure, fundraising, stock market rules and regulations, and legal environment. Reviews the types of minerals exploration companies, differences between mineral sectors, rules and practices of listing a minerals company on a stock exchange, and legal requirements of listing and presenting data to stockholders. The course is centered on lectures by industry representatives from the Denver area. Includes participation in a technical conference in Vancouver or Toronto and meetings with lawyers, stockbrokers, and geoscientists working in the mineral industry. Prerequisites: GEGN401. 3 hours lecture and seminar; 3 semester hours. Offered alternate years when student demand is sufficient.

**GEOL515. ADVANCED MINERAL DEPOSITS. 3.0 Semester Hrs.**
(I) Geology of mineral systems at a deposit, district, and regional scale formed by magmatic-hydrothermal, sedimentary/basinal, and metamorphic processes. Emphasis will be placed on a systems approach to evaluating metal and sulfur sources, transportation paths, and traps. Systems examined will vary by year and interest of the class. Involves a team-oriented research project that includes review of current literature and laboratory research. Prerequisites: GEGN401. 1 hour lecture, 5 hours lab; 3 semester hours. Repeatable for credit.

**GEOL517. FIELD METHODS FOR ECONOMIC GEOLOGY. 3.0 Semester Hrs.**
(II) Methods of field practices related to mineral exploration and mining. Lithology, structural geology, alteration, and mineralization vein-type precious metal deposits. Mapping is conducted both underground at the Edgar Test Mine and above ground in the Idaho Springs area. Drill core and rock chips from different deposit types are utilized. Technical reports are prepared for each of four projects. Class is run on Saturday (9 am-4 pm) throughout the semester. Prerequisites: GEGN401. 6 hours lab and seminar; 3 semester hours. Offered alternate years when student demand is sufficient.

**GEOL518. MINERAL EXPLORATION. 3.0 Semester Hrs.**
(II) Mineral industry overview, deposit economics, target selection, deposit modeling, exploration technology, international exploration, environmental issues, program planning, proposal development. Team development and presentation of an exploration proposal. Prerequisite: GEOL515, GEOL520, or equivalent. 2 hours lecture/seminar, 3 hours lab; 3 semester hours. Offered when student demand is sufficient.

**GEOL519. ABITIBI GEOLOGY AND EXPLORATION FIELD SCHOOL. 3.0 Semester Hrs.**
(II, S) Methods of field practices related to mineral exploration and mining. Regional and deposit-scale geology of Archean mineral deposits, including lode gold deposits and volcanic-hosted massive sulfide deposits. Includes mineral prospect evaluation, structural geology, physical volcanology, deposit definition, alteration mapping, mining methods, ore processing, and metallurgy. Core logging, underground stope mapping, open pit mapping, lithogeochemical sampling, and field-analytical techniques. Course involves a seminar in the spring semester that focuses on the geology and deposit types in the area to be visited. An intense 14-day field trip is run in the summer semester. Each day includes up to 4 hours of instruction in the field and 4 hours of team-oriented field exercises. Prerequisites: none. 6 hours lab and seminar; 2 semester hours in spring, 1 semester hour in summer. Offered alternate years when student demand is sufficient.

**GEOL520. NEW DEVELOPMENTS IN THE GEOLOGY AND EXPLORATION OF ORE DEPOSITS. 2.0 Semester Hrs.**
(I, II, S) Each topic unique and focused on a specific mineral deposit type or timely aspects of economic geology. Review of the geological and geographic setting of a specific magmatic, hydrothermal, or sedimentary mineral deposit type. Detailed study of the physical and chemical characteristics of selected deposits and mining districts. Theory and application of geological field methods and geochemical investigations. Includes a discussion of genetic models, exploration strategies, and mining methods. Prerequisite: GEGN401. 2 hours lecture; 2 semester hours.

**GEOL521. FIELD AND ORE DEPOSIT GEOLOGY. 3.0 Semester Hrs.**
(I, S) Field study of major mineral deposit districts inside and outside of the USA. Examines regional and deposit-scale geology. Underground and open pit mine visits and regional traverses. Topics addressed include deposit definition, structural geology, alteration mapping, mining methods, and ore processing. Course involves a seminar in the spring semester that focuses on the geology and deposit types in the area to be visited. An intense 10-14 day field trip is run in the summer semester. Prerequisites: none. 6 hours lab and seminar; 2 semester hours in spring, 1 semester hour in summer. Offered alternate years when student demand is sufficient. Repeatable for credit.

**GEOL522. TECTONICS AND SEDIMENTATION. 3.0 Semester Hrs.**
(II) Application and integration of advanced sedimentologic and stratigraphic concepts to understand crustal deformation at a wide range of spatial- and time-scales. Key concepts include: growth-strata analysis, interpretation of detrital composition (conglomerate unroofing sequences and sandstone provenance trends), paleocurrent deflection and thinning trends, tectonic control on facies distribution and basic detrital zircon and fission track analysis. Students will read a wide range of literature to explore the utility and limitation of traditional "tectonic signatures" in stratigraphy, and will work on outcrop and subsurface datasets to master these concepts. Special attention is paid to fold-thrust belt, extensional and salt-related deformation. The course has important applications in Petroleum Geology, Geologic Hazards, and Hydrogeology. Required: 2-3 fieldtrips, class presentations, and a final paper that is written in a peer-reviewed journal format. Prerequisites: GEOL314 or equivalent, and GEOL309 or equivalent. 3 hours lecture and seminar; 3 semester hours. Offered even years.

**GEOL523. REFLECTED LIGHT AND ELECTRON MICROSCOPY. 2.0 Semester Hrs.**
(I) Theoretical and practical aspects of reflected light and electron microscopy. Emphasis will be placed on applications to ore deposit exploration and research. Lecture and discussion topics will highlight both standard and new techniques and instrumentation including SEM and QEMSCAN, as well as key questions in mineral deposit genesis which can be addressed using reflected light and electron microscopy. Includes detailed study of a selected suite of samples, with emphasis on mineral identification, textural relationships, paragenetic sequences, and mineral chemistry. Course culminates in a project. Prerequisites: GEGN401. 1 hour lecture; 3 hours lab; 2 semester hours.

**GEOL524. ECONOMIC GEOLOGY. 3.0 Semester Hrs.**
(I) Provides an up-to-date synopsis of the geological settings and characteristics of the major types of magmatic, hydrothermal, and sedimentary metallic ore deposits. Emphasis is placed on the discussion of the source of metals, their transport, and the physical and chemical factors controlling the deposition of metallic ores in different geological environments. Exploration strategies are discussed for each deposit type. Laboratory consists of hand specimen study of host rock and ore mineral suites, optical microscopy, interpretation of phase diagrams, drill core logging, and open pit and underground field investigations. Lectures and laboratories are accompanied by assigned reading. 2 hours lecture; 3 hours lab; 3 semester hours.

**GEOL525. PRINCIPLES OF METAMORPHIC GEOLOGY. 3.0 Semester Hrs.**
(I) Study of metamorphic processes and products that occur on Earth at the micro- to the macro-scale. Areas of focus include (a) the nature of metamorphism in subduction zones and continental interiors, (b) the mechanisms and physico-chemical effects of fluid-rock and melt-rock interactions, (c) links between metamorphism and ore-forming processes, and (d) combining metamorphism with geochemistry, isotope geochronology, and structural geology to quantify the tectonothermal evolution of the lithosphere throughout space and time. Laboratory exercises emphasize the examination, identification, and interpretation of metamorphic minerals and microstructures in hand sample and down the microscope, and the calculation and application of thermodynamically constrained phase equilibria to describe and predict the pressure-temperature evolution of rocks and terranes. Short field excursions to local sites of metamorphic interest. Offered every other year. Prerequisites: GEOL321 and GEGN307. 2 hours lecture; 3 hours lab; 3 semester hours.

**GEOL535. LITHO ORE FORMING PROCESSES. 1.0 Semester Hr.**
Lithogeochemistry is the study of fluid-rock interaction in hydrothermal systems from a mineralogical perspective. Practical 1 credit seminar course were we review mechanisms of metal complexation, transport and mineralization processes in hydrothermal fluids and how they are connected to mineral alteration textures, mineral/rock geochemistry and mineral paragenesis. Students will combine observations of mineral assemblages in rocks and thin sections, and geochemical data to link this knowledge to field observations. The tools provided by this course will enable students to recognize alteration types, establish a mineral paragenesis, and connect alteration features with geochemical changes in bulk rock and mineral chemistry in ore deposits. An extra day will be spent in the field to visit a historic mining district in Colorado. The seminar course comprise also discussions and readings of recent articles and a brief review of hydrothermal-(magmatic) ore deposits (e.g. Greisen alteration, epithermal and porphyry systems, REE and critical metal deposits in (per)alkaline systems, Pb-Zn MVT type deposits). Prerequisite: GEOL321, GEGN401.

**GEOL540. ISOTOPE GEOCHEMISTRY AND GEOCHRONOLOGY. 3.0 Semester Hrs.**

(II) A study of the principles of geochronology and stable isotope distributions with an emphasis on the application of these principles to important case studies in igneous petrology and the formation of ore deposits. U, Th, and Pb isotopes, K-Ar, Rb-Sr, oxygen isotopes, hydrogen isotopes, and carbon isotopes included. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered alternate years.

**GEOL550. INTEGRATED BASIN MODELING. 3.0 Semester Hrs.**

(I) This course introduces students to principal methods in computer-based basin modeling: structural modeling and tectonic restoration; thermal modeling and hydrocarbon generation; and stratigraphic modeling. Students apply techniques to real data set that includes seismic and well data and learn to integrate results from multiple approaches in interpreting a basin's history. The course is primarily a lab course. Prerequisite: none. A course background in structural geology, sedimentology/stratigraphy or organic geochemistry will be helpful. 1 hour lecture, 5 hours labs; 3 semester hours.

**GEOL551. APPLIED PETROLEUM GEOLOGY. 3.0 Semester Hrs.**

(II) Subjects to be covered include computer subsurface mapping and cross sections, petrophysical analysis of well data, digitizing well logs, analyzing production decline curves, creating hydrocarbon-porosity-thickness maps, volumetric calculations, seismic structural and stratigraphic mapping techniques, and basin modeling of hydrocarbon generation. Students are exposed to three software packages used extensively by the oil and gas industry. Prerequisite: GEGN438 or GEOL609. 3 hours lecture; 3 semester hours.

**GEOL552. UNCONVENTIONAL PETROLEUM SYSTEMS. 3.0 Semester Hrs.**

(II) Unconventional petroleum systems have emerged as a critical and indispensable part of current US production and potential future reserves. Each of the 5 unconventional oil and 4 unconventional gas systems will be discussed: what are they, world wide examples, required technology to evaluate and produce, environmental issues, and production/resource numbers. The oil part of the course will be followed by looking at cores from these systems. The gas part of the course will include a field trip to the Denver, Eagle, and Piceance Basins in Colorado to see outstanding outcrops of actual producing units. Prerequisites: GEGN438 or GEOL609, GEGN527. 3 hours lecture; 3 semester hours. Offered alternate years.

**GEOL553. GEOLOGY AND SEISMIC SIGNATURES OF RESERVOIR SYSTEMS. 3.0 Semester Hrs.**

(II) This course is a comprehensive look at the depositional models, log signatures, characteristics, and seismic signatures for all the main reservoirs we explore for and produce from in the subsurface. The first half is devoted to the clastic reservoirs (12 in all); the second part to the carbonate reservoirs (7 total). The course will utilize many hands-on exercises using actual seismic lines for the various reservoir types. Prerequisites: GEOL501 or GEOL314. 3 hours lecture; 3 semester hours. Offered alternate years.

**GEOL555. STRUCTURAL FIELD RESEARCH. 4.0 Semester Hrs.**

(I) This course focuses on geological field work along the Colorado Front Range through inquiry-based research and hypothesis-testing. The type of problems students will work on will vary from more applied problems (e.g. centered around the Edgar mine) or more academic/scientific orientated problems, depending on the student?s interest. The class will be split up in groups of students with similar interests. In the first part of the course, we take an introductory two-day field trip, and students will review existing literature and maps and write a brief research proposal including hypotheses, tests and a work plan for the remainder of the course. The second part of the course will focus on field work. During the last part of the course, students prepare a geological map and appropriate cross sections, and a report presenting rock descriptions, structural analysis, a geological history, and interpretation of results in the context of the hypotheses posed. Prerequisites: (need previous field experience such as a field course, and a course in structural geology and one in earth materials). 2 hours lecture, 6 hours lab; 4 semester hours.

**GEOL557. EARTH RESOURCE DATA SCIENCE 1: FUNDAMENTALS. 3.0 Semester Hrs.**

A hands-on course intended to introduce basic concepts of data science as it pertains to managing surface and subsurface Earth resources, and give examples that can be used in daily geoscience workflows.

**GEOL558. EARTH RESOURCE DATA SCIENCE 2: APPLICATIONS AND MACHINE-LEARNING. 3.0 Semester Hrs.**

Introduction to specific applications (use cases) for Earth resource data science, with examples from the petroleum and minerals industries as well as water resource monitoring and remote-sensing of Earth change. Students are encouraged to provide their own datasets to enable real-world application of the concepts discussed.

**GEOL560. IMPERIAL BARREL AAPG COMPETITION CLASS. 3.0 Semester Hrs.**

(II) The course is designed for geoscience students to evaluate as a team a geophysical and geological dataset. The date set consists of seismic, well data, geochemical information, and geophysical logs. The class provides students with an insight into the hydrocarbon exploration business. A petroleum geology background is useful but not required. A team will compete at the Rocky Mountain Section competition and go onto the Annual American Association of Petroleum Geologist (AAPG) meeting competition if they win the section competition. The class is intended for graduate students only. 3 hours lecture; 3 semester hours.

**GEOL565. RISKS AND VOLUMES ASSESSMENT FOR CONVENTIONAL AND UNCONVENTIONAL PROSPECTS AND PLAYS. 3.0 Semester Hrs.**

(II) Students learn to translate geological knowledge into sound and realistic numbers and ranges for consistent risk and volume assessment of exploration prospects. Prerequisite: GEGN438. 3 hours lecture; 3 semester hours.

**GEOL570. APPLICATIONS OF SATELLITE REMOTE SENSING. 3.0 Semester Hrs.**

(II) An introduction to geoscience applications of satellite remote sensing of the Earth and planets. The lectures provide background on satellites, sensors, methodology, and diverse applications. Topics include visible, near infrared, and thermal infrared passive sensing, active microwave and radio sensing, and geodetic remote sensing. Lectures and labs involve use of data from a variety of instruments, as several applications to problems in the Earth and planetary sciences are presented. Students will complete independent term projects that are presented both written and orally at the end of the term. Prerequisites: PHGN200 and MATH225. 2 hours lecture, 2 hours lab; 3 semester hours.

**GEOL575. PETROLEUM SYSTEMS ANALYSIS. 3.0 Semester Hrs.**
(I, II, S) The goal is to learn how to analyze petroleum systems and use tools of petroleum geochemistry and basin modeling to find, appraise and produce oil and gas. Prerequisites: GEGN438. 3 hours lecture; 3 semester hours.

**GEOL585. APPLICATION OF SEISMIC GEOMORPHOLOGY. 3.0 Semester Hrs.**
(I) Seismic Geomorphology is the study of landforms imaged in 3-D seismic data, for the purpose of understanding the history, processes and fill architecture of a basin. This course will review both qualitative and quantitative approaches to interpreting and applying seismic geomorphologic observations in basin exploration and development. Examples from Gulf of Mexico, Indonesia, Trinidad, Morocco, New Zealand and other basins of the world will be used to illustrate the techniques for interpreting the depositional elements of fluvial, deltaic, shoreline, shelf, deep water clastic systems, as well as delineating geohazards, and for quantifying and using those data to predict reservoir distribution and architecture, body geometries, planning field developments and assessing uncertainty. This introductory look at the tool of seismic geomorphology is suitable for any geoscientists or engineers looking to enhance their understanding of ancient depositional systems imaged in seismic data. 3 hours lecture; 3 semester hours.

**GEOL598. SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING. 3.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**GEOL599. INDEPENDENT STUDY IN GEOLOGY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**GEOL601. CORE TO OUTCROP STRATIGRAPHY. 2.0 Semester Hrs.**
(II) A seminar series integrating core and outcrop observations with class discussions. Topics range from global to regional scale tectono-stratigraphy to process sedimentology. Discussions are based on reading journal papers combined with core observations. Field trip encompasses a series of outcrop-based projects/exercises. Prerequisite: GEOL501. 2 hours seminar; 2 semester hours.

**GEOL608. HISTORY OF GEOLOGICAL CONCEPTS. 3.0 Semester Hrs.**
(I) Lectures and seminars concerning the history and philosophy of the science of geology; emphasis on the historical development of basic geologic concepts. Course is an elective for doctoral candidates in department. 3 hours lecture; 3 semester hours.

**GEOL609. ADVANCED PETROLEUM GEOLOGY. 3.0 Semester Hrs.**
(I) Subjects to be covered involve consideration of basic chemical, physical, biological and geological processes and their relation to modern concepts of oil/gas generation (including source rock deposition and maturation), and migration/accumulation (including that occurring under hydrodynamic conditions). Concepts will be applied to the historic and predictive occurrence of oil/gas to specific Rocky Mountain areas. In addition to lecture attendance, course work involves review of topical papers and solution of typical problems. 3 hours lecture; 3 semester hours. Prerequisite: GEGN438.

**GEOL610. ADVANCED SEDIMENTOLOGY. 3.0 Semester Hrs.**
(I) Keynote lectures, mixed with discussions, in-class exercises, core and field observations in a seminar series on sedimentology. Introduction to current hot topics in sedimentology, and discussions on fundamental principles. Specific topics vary yearly depending on most recent advancements and course participant?s interests. Quantitative sedimentology. Applications of sedimentology. All seminars are based on reading and discussing journal papers. Field trip to a modern environment. Essays and presentations required. Prerequisite: GEOL501. Acceptable to take GEOL610 at the same time, as GEOL501. 3 hours lecture and seminar; 3 semester hours. Offered alternate years.

**GEOL611. SEQUENCE STRATIGRAPHY IN SEISMIC, WELL LOGS, AND OUTCROP. 3.0 Semester Hrs.**
(I) Keynote lectures and a seminar series on the sequence stratigraphy of depositional systems, including both siliciclastics and carbonates and how they behave in changing sea-level, tectonic subsidence, and sediment supply conditions. Application of sequence stratigraphy concepts to reflection seismic, well-log, and outcrop datasets. Field trip and report required. Prerequisite: GEOL501. 3 hours lecture and seminar; 3 semester hours.

**GEOL613. GEOLOGIC RESERVOIR CHARACTERIZATION. 3.0 Semester Hrs.**
(I) Principles and practice of characterizing petro leum reservoirs using geologic and engineering data, including well logs, sample descriptions, routine and special core analysis and well tests. Emphasis is placed on practical analysis of such data sets from a variety of clastic petroleum reservoirs worldwide. These data sets are integrated into detailed characterizations, which then are used to solve practical oil and gas field problems. 3 hours lecture; 3 semester hours. Prerequisite: GEGN438, GEOL501, GEOL505 or equivalents.

**GEOL617. THERMODYNAMICS AND MINERAL PHASE EQUILIBRIA. 3.0 Semester Hrs.**
(I) Basic thermodynamics applied to natural geologic systems. Evaluation of mineral-vapor mineral solution, mineral-melt, and solid solution equilibria with special emphasis on oxide, sulfide, and silicate systems. Experimental and theoretical derivation, use, and application of phase diagrams relevant to natural rock systems. An emphasis will be placed on problem solving rather than basic theory. Prerequisite: DCGN209 or equivalent. 3 hours lecture; 3 semester hours. Offered alternate years.

**GEOL621. PETROLOGY OF DETRITAL ROCKS. 3.0 Semester Hrs.**
(II) Compositions and textures of sandstones, siltstones, and mudrocks. Relationship of compositions and textures of provenance, environment of deposition, and burial history. Development of porosity and permeability. Laboratory exercises emphasize use of petrographic thin sections, x-ray diffraction analysis, and scanning electron microscopy to examine detrital rocks. A term project is required, involving petrographic analysis of samples selected by student. Pre-requisites: GEGN206 , GEOL321 or equivalent. 2 hours lecture and seminar, 3 hours lab; 3 semester hours. Offered on demand.

**GEOL624. CARBONATE SEDIMENTOLOGY AND PETROLOGY. 3.0 Semester Hrs.**

(I) Processes involved in the deposition of carbonate sediments with an emphasis on Recent environments as analogs for ancient carbonate sequences. Carbonate facies recognition through bio- and lithofacies analysis, three-dimensional geometries, sedimentary dynamics, sedimentary structures, and facies associations. Laboratory stresses identification of Recent carbonate sediments and thin section analysis of carbonate classification, textures, non-skeletal and biogenic constituents, diagenesis, and porosity evolution. 2 hours lecture/seminar, 2 hours lab; 3 semester hours. Prerequisite: GEOL321 and GEOL314.

**GEOL628. ADVANCED IGNEOUS PETROLOGY. 3.0 Semester Hrs.**

(I) Igneous processes and concepts, emphasizing the genesis, evolution, and emplacement of tectonically and geochemically diverse volcanic and plutonic occurrences. Tectonic controls on igneous activity and petrochemistry. Petrographic study of igneous suites, mineralized and non-mineralized, from diverse tectonic settings. Prerequisites: GEOL321, GEGN206. 2 hours lecture, 3 hours lab; 3 semester hours. Offered alternate years.

**GEOL642. FIELD GEOLOGY. 1-3 Semester Hr.**

(S) Field program operated concurrently with GEGN316 field camp to familiarize the student with basic field technique, geologic principles, and regional geology of Rocky Mountains. Prerequisite: Undergraduate degree in geology and GEGN316 or equivalent. During summer field session; 1 to 3 semester hours.

**GEOL643. GRADUATE FIELD SEMINARS. 1-3 Semester Hr.**

(I, II, S) Special advanced field programs emphasizing detailed study of some aspects of geology. Normally conducted away from the Golden campus. Prerequisite: Restricted to Ph.D. or advanced M.S. candidates. Usually taken after at least one year of graduate residence. Background requirements vary according to nature of field study. Fees are assessed for field and living expenses and transportation. 1 to 3 semester hours; may be repeated for credit.

**GEOL645. VOLCANOLOGY. 3.0 Semester Hrs.**

(I, II, S) Assigned readings and seminar discussions on volcanic processes and products. Principal topics include pyroclastic rocks, craters and calderas, caldron subsidence, diatremes, volcanic domes, origin and evolution of volcanic magmas, and relation of volcanism to alteration and mineralization. Petrographic study of selected suites of lava and pyroclastic rocks in the laboratory. 1 hour seminar, 6 hours lab; 3 semester hours. Prerequisite: none.

**GEOL653. CARBONATE DIAGENESIS AND GEOCHEMISTRY. 3.0 Semester Hrs.**

(II) Petrologic, geochemical, and isotopic approaches to the study of diagenetic changes in carbonate sediments and rocks. Topics covered include major near-surface diagenetic environments, subaerial exposure, dolomitization, burial diagenesis, carbonate aqueous equilibria, and the carbonate geochemistry of trace elements and stable isotopes. Laboratory stresses thin section recognition of diagenetic textures and fabrics, x-ray diffraction, and geochemical/isotopic approaches to diagenetic problems. Prerequisites: GEOL624. 2 hours lecture; 3 hours lab; 3 semester hours.

**GEOL660. CARBONATE RESERVOIRS - EXPLORATION TO PRODUCTION ENGINEERING. 3.0 Semester Hrs.**

Equivalent with PEGN660,

(II) An introduction to the reservoir characterization of carbonate rocks, including geologic description, petrophysics, and production engineering. Develops an understanding of the integration of geology, rock physics, and engineering to improve reservoir performance. Application of reservoir concepts in hands-on exercises that include reflection seismic, well-log, and core data. 3 hours lecture; 3 semester hours.

**GEOL698. SPECIAL TOPICS. 6.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**GEOL699. INDEPENDENT STUDY IN GEOLOGY. 0.5-6 Semester Hr.**

(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**GEOL707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**

(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

**SYGN588. GIS-BASED REAL WORLD LEARNING PROJECT. 1-6 Semester Hr.**

This course requires a GIS-based project and report that demonstrate competence in the application of GIS to real word problems. The project topic and content of the report is determined by the course instructor, in consultation with the student. The format of the report will follow the guidelines for a professional journal paper. Variable credit: 1 to 6 credit hours. Repeatable for credit under different topics/experience and the cumulative maximum is 6 credit hours and 3 repeats total.

## Professor and Department Head

Wendy Bohrson

## Professors

David A. Benson

Zhaoshan Chang, Charles F. Fogarty Endowed Chair

Wendy J. Harrison

Reed M. Maxwell

Alexei Milkov, Director of Potential Gas Agency

Paul M. Santi

Kamini Singha, Ben Fryrear Endowed Chair for Innovation and Excellence

Stephen A. Sonnenberg, Charles Boettcher Distinguished Chair in Petroleum Geology

Lesli J. Wood, Weimer Distinguished Chair

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Thomas Monecke, Co-Director of CMRS

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## Assistant Professors

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Gabriel Walton

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## Research Professors

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Zane Jobe, Director of the Chevron Center of Research Excellence

David Leach

J. Frederick (Rick) Sarg

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Keenan Lee

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Richard F. Wendlandt

## Associate Professors Emeriti

L. Graham Closs

Timothy A. Cross

Jerry D. Higgins

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# Geophysics

## Degrees Offered

- Professional Masters in Petroleum Reservoir Systems

- Master of Science (Geophysics) (Non-Thesis)
- Master of Science (Geophysical Engineering) (Non-Thesis)

- Master of Science (Geophysics)
- Master of Science (Geophysical Engineering)
- Doctor of Philosophy (Geophysics)
- Doctor of Philosophy (Geophysical Engineering)

## Program Description

Founded in 1926, the Department of Geophysics at Colorado School of Mines is recognized and respected around the world for its programs in applied geophysical research and education.

Geophysics is an interdisciplinary field that blends disciplines such as geology, physics, mathematics, computer science, and electrical engineering. Professionals working in geophysics often come from programs in these allied disciplines, as well as from formal programs in geophysics.

Geophysicists study and explore the interior of the Earth (as well as of other planetary bodies) through physical measurements collected at its surface, in boreholes, from aircraft, and from satellites. Using a combination of mathematics, physics, geology, computer science, hydrology, and chemistry, a geophysicist analyzes these measurements to infer properties and processes within Earth's complex interior. Noninvasive imaging beneath the surface of Earth and other planets by geophysicists is much like the noninvasive imaging of the interior of the human body by medical specialists.

Earth supplies all materials needed by our society, serves as the repository of used products, and provides a home to all its inhabitants. Therefore, geophysics and geophysical engineering have important roles to play in the solution of challenging problems facing the inhabitants of this planet, such as providing fresh water, food, and energy for Earth's growing population, evaluating sites for underground construction and containment of hazardous waste, monitoring noninvasively the aging infrastructures (natural gas pipelines, water supplies, telecommunication conduits, transportation networks) of developed nations, mitigating the threat of geohazards (earthquakes, volcanoes, landslides, avalanches) to populated areas, contributing to homeland security (including detection and removal of unexploded ordnance and land mines), evaluating changes in climate and managing humankind's response to them, and exploring Earth and other planets.

Energy and mining companies employ geophysicists to explore for hidden resources around the world. Engineering firms hire geophysical engineers to assess the Earth's near-surface properties when sites are chosen for large construction projects and waste-management operations. Environmental organizations use geophysics to conduct groundwater surveys and to track the flow of contaminants. On the global scale, geophysicists employed by universities and government agencies (such as the United States Geological Survey and NASA), work to understand Earth processes such as heat flow, gravitational, magnetic, electric, thermal, and stress fields within Earth's interior. For the past decade, 95% of CSM's geophysics graduates have found employment in their chosen field.

With 12 full-time faculty members and small class sizes, students receive individualized attention in a close-knit environment. Given the interdisciplinary nature of geophysics, the graduate curriculum requires students to become thoroughly familiar with geology, physics, mathematics and computer science, in addition to exploring the theoretical and practical aspects of the various geophysical methodologies.

## Research Emphasis

The Department conducts research in a wide variety of areas that are mostly related, but not restricted, to applied geophysics. Candidates interested in the current research activities of specific faculty members are encouraged to visit the Department's website (https://geophysics.mines.edu/) and to contact that faculty member directly. To give prospective candidates an idea of the types of research activities available in geophysics at MINES, a list of the recognized research groups operating within the Department of Geophysics, and information about other research strengths in the Department, is given below.

**The Center for Wave Phenomena (CWP)** in the Department of Geophysics is a research group led by four faculty members, which is supported by the petroleum exploration industry and U.S government agencies. CWP is focused on the development of advanced seismic modeling, imaging, and inversion methods for realistic heterogeneous, anisotropic media. Among the current CWP research topics are wavefield imaging and tomography, waveform inversion of reflection and microseismic data, seismic interferometry and Marchenko imaging, quantification of uncertainty in seismic inversion, seismic fracture characterization, data acquisition using robotics and distributed acoustic sensing (DAS) and applications of geophysical technology to space exploration. CWP faculty and students actively work on large-scale cluster and GPU computing. Further information about CWP can be obtained at https://cwp.mines.edu/.

**The Reservoir Characterization Project (RCP)** integrates the acquisition and interpretation of 3D multicomponent time-lapse seismic reflection and downhole data with geology and petroleum engineering information of existing oil fields to solve complex reservoir challenges and to gain improvements in reservoir performance prediction and development optimization. RCP's unique research model emphasizes a multidisciplinary, collaborative approach for practical research. RCP also focuses on specific research areas such as fiber optics, machine learning, compressive sensing and EOR in unconventionals. It is an industry-funded research consortium with faculty and graduate-level students from Geophysics, Petroleum Engineering, and Geology disciplines. Read more about RCP at http://rcp.mines.edu/.

**The Center for Gravity, Electrical & Magnetic Studies (CGEM)** in the Department of Geophysics is an academic research center that focuses on the quantitative interpretation of gravity, magnetic, electrical and electromagnetic, and surface nuclear magnetic resonance (NMR) data in applied geophysics. The Center brings together the diverse expertise of faculty and students in these different geophysical methods and works towards advancing the state of art in geophysical data interpretation for real-world problems. The emphases of CGEM research are processing and inversion of applied geophysical data. The primary areas of application include petroleum exploration and production, mineral exploration, geothermal, and geotechnical and engineering problems. In addition, environmental problems, infrastructure mapping, archaeology, hydrogeophysics, and crustal studies are also research areas within the Center. There are currently five major focus areas of research within CGEM: Gravity and Magnetics Research Consortium (GMRC), mineral exploration, geothermal exploration, surface NMR, and hydrogeophysics. Research funding is provided by petroleum and mining industries, ERDC, SERDP, DOE, and other agencies. More information about CGEM is available on the web at: http://cgem.mines.edu/.

**The Center for Rock Abuse** at the Colorado School of Mines focuses on fluid distributions in rocks and how these distributions affect characteristics such as wave attenuation, velocity dispersion, and seismic signature. The Center uses a range of instrumentation through the Rock Lab in the Green Center, including low-frequency devices, laser optics equipment, and x-ray computed tomography equipment. The Center manages two major research consortia. For more information, visit https://crusher.mines.edu/.

**The Electromagnetic Resource Exploration Group (EMREX)** at the Colorado School of Mines focuses on may aspects of applied electromagnectic methods in geophysics. Projects in which we are currently involved include the effects of steel oil & gas infrastructure (such as casing and pipelines) on controlled-source electromagnetic (CSEM) surveys, marine mineral exploration, powerline contamination of airborne electromagnetic data magnetic storm hazard assessment for electrical power grids, and look-ahead geophysical methods during underground tunneling & construction.

**The Global and Computational Seismology Group** at the Colorado School of Mines focuses on investigating Earth's interior and other planetary bodies using passive seismic sources, such as quakes and ambient noise. Harnessing the opportunities provided by high-performance computing, ever-increasing seismic data, the group analyzes seismic wiggles and construct high-resolution CAT scan images of Earth's interior to interpret the composition & inner dynamics of our planet, and relate them to surface processes to understand the origin of and the driving forces behind tectonic activities. These studies also have strong societal impact including assessment and mitigation of natural hazards related to seismic activity and tsunamis in earthquake-prone regions. The experience gained from our planet is also used to inspect the composition and dynamics of Mars and Moon. Research interests of the group include (numerical) simulations of seismic wave propagation & full-waveform inversion (FWI) from regional to global scales; seismic tomography with emerging data sets (i.e., from floating robots and distributed acoustic sensors, environmental noise, etc.); multi-scale structure, anisotropy, and anelasticity of Earth's mantle, D'' region and core; seismic hazard analysis; planetary seismology.

**Hydrogeophysics and porous media** research focuses on combining ground-penetrating radar, electrical, and seismic measurements with rock physics models at various scales and for various applications including the study of contaminant plumes, geothermal systems, leakage in earth dams and embankments, and active volcanoes.

**Cryopshere Geophysics** aims to understand physical processes of glaciers, ice sheets, snow, permafrost, and sea ice on Earth and other planetary bodies, using ground-, air-, and space-based geophysical methods. Cryosphere geophysical research at Colorado School of Mines particularly tries to understand how these frozen bodies interact with other physical systems, such as oceans, atmosphere, and groundwater on Earth or past climate on Mars.

## Program Requirements

The Department offers both traditional, research-oriented graduate programs and a non-thesis professional education program designed to meet specific career objectives. The program of study is selected by the student, in consultation with an advisor, and with thesis committee approval, according to the student's career needs and interests. Specific degrees have specific requirements as detailed below.

## Geophysics and Geophysical Engineering Program Objectives

The principal objective for students pursuing the PhD degree in Geophysics or Geophysical Engineering is: Geophysics PhD graduates will be regarded by their employers as effective educators and/or innovative researchers in their early-career peer group. In support of this objective, the PhD programs in the Department of Geophysics are aimed at achieving these student outcomes:

- Graduates will command superior knowledge of Geophysics and fundamental related disciplines.
- Graduates will independently be able to conduct research leading to significant new knowledge and Geophysical techniques.
- Graduates will be able to report their findings orally and in writing.

The chief objective for students pursuing the MS degree in Geophysics or Geophysical Engineering is: Geophysics MS graduates will be regarded by their employers as effective practitioners addressing earth, energy and environmental problems with geophysical techniques. In support of this objective, the MS programs in the Department of Geophysics aim to achieve these student outcomes:

- Graduates will command superior knowledge of Geophysics and fundamental related disciplines.
- Graduates will be able to conduct original research that results in new knowledge and Geophysical techniques.
- Graduates will be able to report their findings orally and in writing.

## Master of Science Degrees (Non-Thesis): Geophysics and Geophysical Engineering

Students may obtain a Master of Science (MS) Degree (Non-Thesis) in either Geophysics or Geophysical Engineering, pursuant to the general and individual program requirements outlined below.

For either Master of Science (Non-Thesis) degree, the minimum credits required include:

| | | |
|---|---|---|
| LICM501 | PROFESSIONAL ORAL COMMUNICATION | 1.0 |
| GPGN530 | APPLIED GEOPHYSICS | 3.0 |
| GPGN536 | ADVANCED GEOPHYSICAL COMPUTING I | 3.0 |
| GPGN581 | GRADUATE SEMINAR | 1.0 |
| GPGN5XX | Readings (research) Seminar | 1.0 |
| GPGN605 | INVERSION THEORY | 3.0 |
| GPGNXXX | Additional Course credits | 18.0 |
| Total Semester Hrs | | 30.0 |

The student and advisor determine individual courses constituting the degree. The courses applied to all MS degrees must satisfy the following specific criteria:

- All course, transfer, residence, and thesis requirements are as described in Registration and Tuition Classification and Graduate Degrees and Requirements sections of the Catalog.
- Up to 6 credits of 400 or 500 level work may be double counted in the undergraduate and graduate degree for students enrolled in the Combined Degree.
- Up to 9 credits may be satisfied through 400 (senior) level coursework. All remaining course credits applied to the degree must be at the 500 level or above.
- Additional courses may also be required by the student's advisor and committee to fulfill background requirements.
- Students must complete, either prior to their arrival at Mines or while at Mines, no fewer than 16 credits of engineering coursework. What constitutes coursework considered as engineering is determined by the Geophysics faculty.

## Computational Geophysics Track

Students in the Geophysics Non-Thesis Master's Degree program, Computational Geophysics Track, will be expected to complete the following:

| | | |
|---|---|---|
| GPGNXXXX | Required Courses | 12.0 |
| GPGNXXXX | GPGN Approved Elective Courses (500+ level) | 6.0 |
| CSMXXXX | CSM Approved Elective Courses (500+ level) | 12.0 |
| Total Semester Hrs | | 30.0 |

The **Required Courses** for the program are:

| | | |
|---|---|---|
| GPGN530 | APPLIED GEOPHYSICS | 3.0 |
| GPGN536 | ADVANCED GEOPHYSICAL COMPUTING I | 3.0 |
| GPGN605 | INVERSION THEORY | 3.0 |
| LICM501 | PROFESSIONAL ORAL COMMUNICATION | 1.0 |
| GPGN581 | GRADUATE SEMINAR | 1.0 |
| GPGN5XX | Readings (research) Seminar | 1.0 |

The **Approved GPGN Electives** with a significant computational component are:

| | | |
|---|---|---|
| GPGN533 | GEOPHYSICAL DATA INTEGRATION & GEOSTATISTICS | 3.0 |
| GPGN537 | ADVANCED GEOPHYSICAL COMPUTING II | 3.0 |
| GPGN555 | EARTHQUAKE SEISMOLOGY | 3.0 |
| GPGN570 | APPLICATIONS OF SATELLITE REMOTE SENSING | 3.0 |
| GPGN658 | SEISMIC WAVEFIELD IMAGING | 3.0 |

The **Approved CSM Electives** are:

| | | |
|---|---|---|
| MATH540 | PARALLEL SCIENTIFIC COMPUTING | 3.0 |
| MATH550 | NUMERICAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS | 3.0 |
| MATH551 | COMPUTATIONAL LINEAR ALGEBRA | 3.0 |
| CSCI403 | DATA BASE MANAGEMENT | 3.0 |
| CSCI470 | INTRODUCTION TO MACHINE LEARNING | 3.0 |
| or CSCI575 | MACHINE LEARNING | |
| CSCI542 | SIMULATION | 3.0 |
| CSCI568 | DATA MINING | 3.0 |
| CSCI580 | ADVANCED HIGH PERFORMANCE COMPUTING | 3.0 |
| EENG509 | SPARSE SIGNAL PROCESSING | 3.0 |
| EENG511 | CONVEX OPTIMIZATION AND ITS ENGINEERING APPLICATIONS | 3.0 |
| EENG515 | MATHEMATICAL METHODS FOR SIGNALS AND SYSTEMS | 3.0 |

## Master of Science Degrees: Geophysics and Geophysical Engineering

Students may obtain a Master of Science (MS) Degree in either Geophysics or Geophysical Engineering, pursuant to the general and individual program requirements outlined below.

For either Master of Science degree, the minimum credits required include:

| | | |
|---|---|---|
| LICM501 | PROFESSIONAL ORAL COMMUNICATION | 1.0 |
| GPGN530 | APPLIED GEOPHYSICS | 3.0 |
| GPGN536 | ADVANCED GEOPHYSICAL COMPUTING I | 3.0 |
| GPGN581 | GRADUATE SEMINAR | 1.0 |
| GPGN5XX | Readings (research) Seminar | 1.0 |
| GPGN605 | INVERSION THEORY | 3.0 |
| GPGNXXX | Additional Course credits | 12.0 |
| GPGN707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 6.0 |
| Total Semester Hrs | | 30.0 |

The student and advisor, with approval from the thesis committee, determines individual courses constituting the degree. The courses applied to all MS degrees must satisfy the following specific criteria:

- All course, research, transfer, residence, and thesis requirements are as described in Registration and Tuition Classification and Graduate Degrees and Requirements sections of the Catalog.
- Up to 6 credits of 400 or 500 level work may be double counted in the undergraduate and graduate degree for students enrolled in the Combined Degree.
- Up to 9 credits may be satisfied through 400 (senior) level coursework. All remaining course credits applied to the degree must be at the 500 level or above.
- Additional courses may also be required by the student's advisor and committee to fulfill background requirements.

The coursework and thesis topic for the degree Master of Science, Geophysical Engineering, must meet the following specific requirements. Note that these requirements are in addition to those associated with the Master of Science in Geophysics.

- Students must complete, either prior to their arrival at Mines or while at Mines, no fewer than 16 credits of engineering coursework. What constitutes coursework considered as engineering is determined by the Geophysics faculty.

- The student's dissertation topic must be appropriate for inclusion as part of an Engineering degree, as determined by the Geophysics faculty.

As described in the Master of Science, Thesis and Thesis Defense section of this Catalog, all MS candidates must successfully defend their MS thesis in a public oral Thesis Defense. The guidelines for the Thesis Defense enforced by the Department of Geophysics generally follow those outlined in in the Graduate Departments and Programs section of the Catalog, with one exception. The Department of Geophysics requires students submit the final draft of their written thesis to their thesis committee a minimum of three weeks prior to the thesis defense date.

## Professional Masters in Petroleum Reservoir Systems

The Professional Masters in Petroleum Reservoir Systems (PMPRS) degree is designed for individuals who have petroleum industry experience and are interested in increasing their knowledge across the disciplines of geology, geophysics, and petroleum engineering. This is an interdisciplinary, non-thesis master's degree for students interested in working as geoscience professionals in the petroleum industry. Details including program requirements and description can be found on the Interdisciplinary section of the catalog or by searching for Petroleum Reservoir Systems.

## Mines' Combined Undergraduate/Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any courses that count towards the graduate degree requirements as either "Required Coursework" or "Elective Coursework", as defined below, may be used for the purposes of double counting at the discretion of the advisor (MS Non-Thesis) or thesis committee (MS Thesis or PhD). These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit.

## Doctor of Philosophy Degrees: Geophysics and Geophysical Engineering

We invite applications to our Doctor of Philosophy (PhD) program not only from those individuals with a background in geophysics, but also from those whose background is in allied disciplines such as geology, physics, mathematics, computer science, or electrical engineering.

Students may obtain a PhD Degree in either Geophysics or Geophysical Engineering, pursuant to the general and individual program requirements outlined below.

For either PhD degree, at least 72 credits beyond the Bachelors Degree are required. Of that total, at least 24 research credits are required. At least 12 course credits must be completed in a minor program of study, approved by the candidate's PhD thesis committee. Up to 36 course credits may be awarded by the candidate's committee for completion of a thesis-based Master's Degree.

While individual courses constituting the degree are determined by the student and approved by the student's advisor and committee, courses applied to all PhD degrees must satisfy the following criteria:

- All course, research, minor degree programs, transfer, residence, and thesis requirements are as described in Registration and Tuition Classification and Graduate Degrees and Requirements sections of the Catalog.
- Up to 9 credits may be satisfied through 400 (senior) level coursework. All remaining course credits applied to the degree must be at the 500 level or above.
- Students must include the following courses in their PhD program:

| | | |
|---|---|---|
| LICM501 | PROFESSIONAL ORAL COMMUNICATION | 1.0 |
| SYGN502 | INTRODUCTION TO RESEARCH ETHICS | 1.0 |
| GPGN681 | GRADUATE SEMINAR - PHD | 1.0 |
| GPGN707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 24.0 |
| Choose two of the following: | | |
| SYGN501 | RESEARCH SKILLS FOR GRADUATE STUDENTS | 1.0 |
| SYGN600 | COLLEGE TEACHING | 2.0 |
| HASS601 | ACADEMIC PUBLISHING | 2-3 |

- Additional courses may also be required by the student's advisor and committee to fulfill background requirements described below.

The coursework and thesis topic for the degree Doctor of Philosophy, Geophysical Engineering, must meet the following additional requirements:

- Students must complete, either prior to their arrival at Mines or while at Mines, no fewer than 16 credits of engineering coursework. What constitutes coursework considered as engineering is determined by the Geophysics faculty.
- The student's dissertation topic must be appropriate for inclusion as part of an Engineering degree, as determined by the Geophysics faculty.

Students in both PhD programs are also required to participate in a practical teaching experience. This requirement must be fulfilled, within a single semester and course, under observation and evaluation by the course instructor of record, and include:

- Planning and delivery of a minimum of 6 lecture hours, or 4 lecture hours and 2 labs;
- Creating and evaluating students' homework and laboratory reports, if appropriate; and
- Holding office hours if necessary.

In both PhD programs, students must demonstrate the potential for successful completion of independent research and enhance the breadth of their expertise by completing a Doctoral Research Qualifying Examination not later than two years from the date of enrollment in the program. An extension of one additional year may be petitioned by students through their thesis committees. In the Department of Geophysics, the Doctoral Research Qualifying Examination consists of the preparation, presentation, and defense of one research project and a thesis proposal. The research project and thesis proposal used in this process must conform to the standards posted on the Department of Geophysics website. As described in the Doctor of Philosophy Thesis

Defense section of this catalog, all PhD candidates must successfully defend their PhD thesis in an open oral Thesis Defense. The guidelines for the Thesis Defense enforced by the Department of Geophysics follow those outlined in the Graduate Departments and Programs section of the Catalog, with one exception. The Department of Geophysics requires students submit the final draft of their written thesis to their thesis committee a minimum of three weeks prior to the thesis defense date.

### Acceptable Thesis Formats

In addition to traditional dissertations, the Department of Geophysics also accepts dissertations that are compendia of papers published or submitted to peer-reviewed journals. Dissertations submitted in the latter format must adhere to the following guidelines.

- All papers included in the dissertation must have a common theme, as approved by a student's thesis committee.
- Papers should be submitted for inclusion in a dissertation in a uniform format and typeset.
- In addition to the individual papers, students must prepare abstract, introduction, discussion, and conclusions sections of the thesis that tie together the individual papers into a unified dissertation.
- A student's thesis committee might also require the preparation and inclusion of various appendices with the dissertation in support of the papers prepared explicitly for publication.

## Graduate Program Background Requirements

All graduate programs in Geophysics require that applicants have a background that includes the equivalent of adequate undergraduate preparation in the following areas:

- Mathematics – Linear Algebra or Linear Systems, Differential Equations, and Computer Programming
- Physics – Classical Mechanics, and Electromagnetism
- Geology – Structural Geology and Stratigraphy
- Geophysics – Courses that include theory and application in three of the following areas: gravity/magnetics, seismic, electrical/ electromagnetics, borehole geophysics, remote sensing, and geodynamics.
- Field experience in the hands-on application of several geophysical methods
- In addition, candidates in the Doctoral program are required to have no less than one year of college-level or two years of high-school-level courses in a single foreign language, or be able to demonstrate fluency in at least one language other than English.

## Courses

**GPGN503. INTEGRATED EXPLORATION AND DEVELOPMENT. 3.0 Semester Hrs.**
(I) Students work alone and in teams to study reservoirs from fluvial-deltaic and valley fill depositional environments. This is a multidisciplinary course that shows students how to characterize and model subsurface reservoir performance by integrating data, methods and concepts from geology, geophysics and petroleum engineering. Activities include field trips, computer modeling, written exercises and oral team presentations. Prerequisite: none. 2 hours lecture, 3 hours lab; 3 semester hours. Offered fall semester, odd years.

**GPGN504. INTEGRATED EXPLORATION AND DEVELOPMENT. 3.0 Semester Hrs.**
(I) Students work in multidisciplinary teams to study practical problems and case studies in integrated subsurface exploration and development. The course addresses emerging technologies and timely topics with a general focus on carbonate reservoirs. Activities include field trips, 3D computer modeling, written exercises and oral team presentation. Prerequisite: none. 3 hours lecture and seminar; 3 semester hours. Offered fall semester, even years.

**GPGN509. PHYSICAL AND CHEMICAL PROPERTIES AND PROCESSES IN ROCK, SOILS, AND FLUIDS. 3.0 Semester Hrs.**
(I) Physical and chemical properties and processes that are measurable with geophysical instruments are studied, including methods of measurement, interrelationships between properties, coupled processes, and processes which modify properties in pure phase minerals and fluids, and in mineral mixtures (rocks and soils). Investigation of implications for petroleum development, minerals extraction, groundwater exploration, and environmental remediation. Prerequisite: none. 3 hours lecture, 3 semester hours.

**GPGN511. ADVANCED GRAVITY AND MAGNETIC METHODS. 3.0 Semester Hrs.**
This course presents the theory and methods for processing and interpreting gravity and magnetic data acquired in geoscience applications. The course covers four major topic areas in the gravity and magnetic methods: (1) the data quantities measured in field surveys; (2) the methods for modeling, processing, and analyzing gravity, gravity gradient, and magnetic data; (3) 3D inversion of gravity and magnetic data; and (4) integrated interpretation of gravity and magnetic data through inversion and geology differentiation for extracting geology information. Prerequisites: GPGN314, GPGN328.

**GPGN519. ADVANCED FORMATION EVALUATION. 3.0 Semester Hrs.**
A detailed review of well logging and other formation evaluation methods will be presented, with the emphasis on the imaging and characterization of hydrocarbon reservoirs. Advanced logging tools such as array induction, dipole sonic, and imaging tools will be discussed. The second half of the course will offer in parallel sessions: for geologists and petroleum engineers on subjects such as pulsed neutron logging, nuclear magnetic resonance, production logging, and formation testing; for geophysicists on vertical seismic profiling, cross well acoustics and electro-magnetic surveys. Prerequisite: GPGN419/PEGN419.

**GPGN520. ELECTRICAL AND ELECTROMAGNETIC EXPLORATION. 3.0 Semester Hrs.**
(II) Electromagnetic theory. Instrumentation. Survey planning. Processing of data. Geologic interpretations. Methods and limitations of interpretation. Offered Spring semester in conjunction with GPGN420. Prerequisite: GPGN314. 3 hours lecture; 3 semester hours.

**GPGN530. APPLIED GEOPHYSICS. 3.0 Semester Hrs.**
(II) Introduction to geophysical techniques used in a variety of industries (mining, petroleum, environmental and engineering) in exploring for new deposits, site design, etc. The methods studied include gravity, magnetic, electrical, seismic, radiometric and borehole techniques. Emphasis on techniques and their applications are tailored to student interests. The course, intended for non-geophysics students, will emphasize the theoretical basis for each technique, the instrumentation used and data collection, processing and interpretation procedures specific to each technique so that non-specialists can more effectively evaluate the results of geophysical investigations. Prerequisites: PHGN100, PHGN200, MATH111, GEGN401. 3 hours lecture; 3 semester hours.

**GPGN533. GEOPHYSICAL DATA INTEGRATION & GEOSTATISTICS. 3.0 Semester Hrs.**

(I) Students will learn the fundamentals of and explore opportunities for further development of geostatistical data integration techniques for subsurface earth modeling. The class will build on probability theory, spatial correlations and geostatistics algorithms for combing data of diverse support and resolution into subsurface models. The emphasis of the material will be on stochastic methods for combining quantitative and qualitative data into many equi-probable realizations. Activities include computer modeling, written exercises, oral team presentations, and a semester project with opportunity to enhance student?s respective research projects. Also, we will read, discuss and implement current research articles the in literature to encourage implementation of state-of-the-art practices and/or highlighting current opportunities for research. 3 hours lecture; 3 semester hours.

**GPGN536. ADVANCED GEOPHYSICAL COMPUTING I. 3.0 Semester Hrs.**

This course extends the principles of geophysical computing in the context of simulating and validating numerical solutions to geophysical data processing challenges and 2D/3D partial differential equations commonly found in geophysical investigations. Students develop 2D and 3D numerical solutions to geophysical problems through prototyping and validating code in both high- (e.g., Python) and low-level (e.g., C/C++/F90) languages. Offered in conjunction with GPGN435. Prerequisite: CSCI250 or instructor consent.

**GPGN537. ADVANCED GEOPHYSICAL COMPUTING II. 3.0 Semester Hrs.**

A survey of computer programming skills most relevant to geophysical modeling, data processing, visualization, and analysis. Skills enhanced include effective use of multiple programming languages, multicore systems, computer memory hierarchies, GPUs, and parallel computing strategies. Problems addressed include multidimensional geophysical partial differential equations, geophysical image processing, regularization of geophysical data acquired at scattered locations, and other geophysical computing problems encountered in research by students. Prerequisite: GPGN536 or instructor consent.

**GPGN547. PHYSICS, MECHANICS, AND PETROPHYSICS OF ROCKS. 3.0 Semester Hrs.**

This course will discuss topics in rock physics, rock mechanics and petrophysics as outlined below. The class is a combination of lectures, practical sessions, and critical reading and discussion of papers. Topics addressed: Segment in Rock physics: stress, strain, stiffness, modulus, attenuation and dispersion, Segment in Petrophysics: seismic & log expression of various formations, wettability, shale analysis, diagenesis, formation evaluation.

**GPGN551. WAVE PHENOMENA SEMINAR. 1.0 Semester Hr.**

(I, II) Students will probe a range of current methodologies and issues in seismic data processing, and discuss their ongoing and planned research projects. Topic areas include: Statics estimation and compensation, deconvolution, multiple suppression, wavelet estimation, imaging and inversion, anisotropic velocity and amplitude analysis, seismic interferometry, attenuation and dispersion, extraction of stratigraphic and lithologic information, and correlation of surface and borehole seismic data with well log data. Every student registers for GPGN551 in only the first semester in residence and receives a grade of PRG. The grade is changed to a letter grade after the student's presentation of thesis research. Prerequisite: none. 1 hour seminar; 1 semester hour.

**GPGN552. INTRODUCTION TO SEISMOLOGY. 3.0 Semester Hrs.**

(I) Introduction to basic principles of elasticity including Hooke?s law, equation of motion, representation theorems, and reciprocity. Representation of seismic sources, seismic moment tensor, radiation from point sources in homogeneous isotropic media. Boundary conditions, reflection/transmission coefficients of plane waves, plane-wave propagation in stratified media. Basics of wave propagation in attenuative media, brief description of seismic modeling methods. Prerequisite: GPGN461. 3 hours lecture; 3 semester hours.

**GPGN553. INTRODUCTION TO SEISMOLOGY. 3.0 Semester Hrs.**

(II) This course is focused on the physics of wave phenomena and the importance of wave-theory results in exploration and earthquake seismology. Includes reflection and transmission problems for spherical waves, methods of steepest descent and stationary phase, point-source radiation in layered isotropic media, surface and non-geometrical waves. Discussion of seismic modeling methods, fundamentals of wave propagation in anisotropic and attenuative media. Prerequisite: GPGN552. 3 hours lecture; 3 semester hours. Offered spring semester, even years.

**GPGN555. EARTHQUAKE SEISMOLOGY. 3.0 Semester Hrs.**

Equivalent with GPGN455,

(I) Earthquakes are amongst the most significant natural hazards faced by mankind, with millions of fatalities forecast this century. They are also our most accessible source of information on Earth's structure, rheology and tectonics, which are what ultimately govern the distribution of its natural resources. This course provides an overview of how earthquake seismology, complemented by geodesy and tectonic geomorphology, can be used to determine Earth structure, earthquake locations, depths and mechanisms; understand Earth's tectonics and rheology; establish long-term earthquake histories and forecast future recurrence; and mitigate against seismic hazards. GPGN555 differs from GPGN455 in that the assignments are approximately 20% longer and encompass more challenging questions. GPGN555 is the appropriate course for graduate students and for undergraduates who expect to go on to study earthquake seismology at graduate school. 3 hours lecture; 3 semester hours. Prerequisite: GPGN320.

**GPGN558. SEISMIC DATA INTERPRETATION AND QUANTITATIVE ANALYSIS. 3.0 Semester Hrs.**

This course gives participants an understanding of how to model, understand, interpret and analyze seismic data in a quantitative manner on several worldwide projects. When you look at seismic data, how does it relate to the rock properties, what do the amplitudes mean, what is tuning, what is a wavelet, how does the seismic relate to structure, and what are seismic attributes and inversion products? How do you use this information in exploration, production and basic volumetric and economics calculations? The course will go over these topics. Students will work in teams on several modeling and seismic field data exercises around the world in most widely used software platforms (Ikon-RokDoc, Schlumberger-Petrel, GEOX, CGG-HampsonRussell). The course aims to give participants knowledge and information to assist in professional and career development and to be operationally prepared for the work environment.

**GPGN561. SEISMIC DATA PROCESSING I. 3.0 Semester Hrs.**
(I) Introduction to basic principles underlying the processing of seismic data for suppression of various types of noise. Includes the rationale for and methods for implementing different forms of gain to data, and the use of various forms of stacking for noise suppression, such as diversity stacking of Vibroseis data, normal-moveout correction and common-midpoint stacking, optimum-weight stacking, beam steering and the stack array. Also discussed are continuous and discrete oneand two-dimensional data filtering, including Vibroseis correlation, spectral whitening, moveout filtering, data interpolation, slant stacking, and the continuous and discrete Radon transform for enhancing data resolution and suppression of multiples and other forms of coherent noise. Prerequisite: GPGN461. 3 hours lecture; 3 semester hours.

**GPGN570. APPLICATIONS OF SATELLITE REMOTE SENSING. 3.0 Semester Hrs.**
(II) An introduction to geoscience applications of satellite remote sensing of the Earth and planets. The lectures provide background on satellites, sensors, methodology, and diverse applications. Topics include visible, near infrared, and thermal infrared passive sensing, active microwave and radio sensing, and geodetic remote sensing. Lectures and labs involve use of data from a variety of instruments, as several applications to problems in the Earth and planetary sciences are presented. Students will complete independent term projects that are presented both written and orally at the end of the term. Prerequisites: PHGN200 and MATH225. 2 hours lecture, 2 hours lab; 3 semester hours.

**GPGN574. ADVANCED HYDROGEOPHYSICS. 3.0 Semester Hrs.**
(I) Application of geophysical methods to problems in hydrology. Effects of water saturation on the physical properties of rocks. Use of geophysical methods in the exploration, development and production of groundwater, groundwater surface water interaction, snow and ice as a water resource, delineation of groundwater contamination, and mapping of saltwater intrusion. Introduction to the equations governing groundwater flow. Application of inversion to geophysical data to estimate hydrologic parameters.Prerequisite: GPGN 409. 3 hours lecture; 3 semester hours.

**GPGN577. HUMANITARIAN GEOSCIENCE. 3.0 Semester Hrs.**
This interdisciplinary course introduces the concepts and practice of geoscientific investigations in humanitarian projects. Students will evaluate humanitarian geoscience case studies, devise the characteristics of successful projects, and identify how these best practices could improve previous case studies. This knowledge will be applied towards a group project. Students will split into groups and pair up with a faculty advisor and a local organization (e.g., NGO or community group) to design, execute and assess the impact of their project. A key emphasis in all aspects of the course will be on community engagement. This course is taught in collaboration with the Mines Engineering Design and Society Division and other participating departments. Prerequisite: GPGN 486 Field Camp; CEEN 330 Engineering Field Session, Environmental; or equivalent accredited field session or applicable field experience as approved course instructor.

**GPGN581. GRADUATE SEMINAR. 1.0 Semester Hr.**
(I, II) Attendance at scheduled weekly Heiland Distinguished Lectures during each semester of enrollment. Students must complete one individual presentation during the graduate program, at an approved public venue, before degree is granted. Every thesis-based MS student in Geophysics and Geophysical Engineering registers each semester in residence in the program and receive 0.0 credit hours until the last semester in residence. For the last semester, 1.0 credit hours and a grade of PRG are awarded with satisfactory attendance and successful completion of individual presentation requirement. 1 hour seminar; 0 or 1 semester hours.

**GPGN590. INSTRUMENTAL DESIGN IN APPLIED GEOPHYSICS. 3.0 Semester Hrs.**
(I) A hands-on course on instrumental design in applied geophysics. The first half of the course consists of basic electronic concepts to familiarize students with the skills needed to build instruments (such as DC circuits, AC circuits, amplifiers and digital electronics). The second half of the course consists a project (or projects) of the students choosing, where they build simple geophysical instruments such as a fluxgate magnetometer or a resistivity system. Prerequisite: None, although Applied Geophysics is recommended. 2.5 hours lecture; 1.5 hours lab; 3 semester hours.

**GPGN598. SPECIAL TOPICS IN GEOPHYSICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**GPGN599. GEOPHYSICAL INVESTIGATIONS MS. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**GPGN605. INVERSION THEORY. 3.0 Semester Hrs.**
(II) Introductory course in inverting geophysical observations for inferring earth structure and processes. Techniques discussed include: Monte-Carlo procedures, Marquardt-Levenburg optimization, and generalized linear inversion. In addition, aspects of probability theory, data and model resolution, uniqueness considerations, and the use of a priori constraints are presented. Students are required to apply the inversion methods described to a problem of their choice and present the results as an oral and written report. Prerequisite: MATH225 and knowledge of a scientific programming language. 3 hours lecture; 3 semester hours.

**GPGN651. ADVANCED SEISMOLOGY. 3.0 Semester Hrs.**
(I) In-depth discussion of wave propagation and seismic processing for anisotropic, heterogeneous media. Topics include influence of anisotropy on plane-wave velocities and polarizations, traveltime analysis for transversely isotropic models, anisotropic velocity-analysis and imaging methods, point-source radiation and Green?s function in anisotropic media, inversion and processing of multicomponent seismic data, shear-wave splitting, and basics of seismic fracture characterization. Prerequisites: GPGN552 and GPGN553. 3 hours lecture; 3 semester hours.

**GPGN658. SEISMIC WAVEFIELD IMAGING. 3.0 Semester Hrs.**
(I) Seismic imaging is the process that converts seismograms, each recorded as a function of time, to an image of the earth's subsurface, which is a function of depth below the surface. The course emphasizes imaging applications developed from first principles (elastodynamics relations) to practical methods applicable to seismic wavefield data. Techniques discussed include reverse-time migration and migration by wavefield extrapolation, angle-domain imaging, migration velocity analysis and analysis of angle-dependent reflectivity. Students do independent term projects presented at the end of the term, under the supervision of a faculty member or guest lecturer. Prerequisite: none. 3 hours lecture; 3 semester hours.

**GPGN681. GRADUATE SEMINAR - PHD. 1.0 Semester Hr.**
(I,II) Presentation describing results of PhD thesis research. All students must present their research at an approved public venue before the degree is granted. Every PhD student registers for GPGN681 only in his/her first semester in residence and receives a grade of PRG. Thereafter, students must attend the weekly Heiland Distinguished Lecture every semester in residence. The grade of PRG is changed to a letter grade after the student's public research presentation and thesis defense are both complete. 1 hour seminar; 1 semester hour.

**GPGN698. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**GPGN699. GEOPHYSICAL INVESTIGATION-PHD. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**GPGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

**SYGN501. RESEARCH SKILLS FOR GRADUATE STUDENTS. 1.0 Semester Hr.**
(I, II) This course consists of class sessions and practical exercises. The content of the course is aimed at helping students acquire the skills needed for a career in research. The class sessions cover topics such as the choice of a research topic, making a work plan and executing that plan effectively, what to do when you are stuck, how to write a publication and choose a journal for publication, how to write proposals, the ethics of research, the academic career versus a career in industry, time-management, and a variety of other topics. The course is open to students with very different backgrounds; this ensures a rich and diverse intellectual environment. Prerequisite: None. 1 hour lecture; 1 semester hour.

## Professors

John H. Bradford, Vice Provost of Global Initiatives and Dean of Earth Resources and Environmental Programs

Yaoguo Li

Manika Prasad

Paul C. Sava, Interim Department Head, C.H. Green Chair of Exploration Geophysics

Roelof K. Snieder, W.M. Keck Distinguished Professor of Professional Development Education

Ilya D. Tsvankin

Ali Tura

## Associate Professors

Brandon Dugan, Associate Department Head, Baker Hughes Chair of Petrophysics and Borehole Geophysics

Jeffrey C. Shragge

Andrei Swidinsky

## Assistant Professors

Ebru Bozdag

Ge Jin

Matthew Siegfried

## Professors Emeriti

Norman Bleistein

Thomas L. Davis

Dave Hale

Alexander A. Kaufman

Kenneth L. Larner

Gary R. Olhoeft

Phillip R. Romig, Jr.

Terence K. Young

## Associate professor emeritus

Thomas M. Boyd

## Research Professor

Jeffrey Lee

## Research Associate Professor

James L. Simmons

## Research Assistant Professors

Jyoti Behura

Richard Krahenbuhl

Mathias Pohl

Whitney Trainor-Guitton

## Adjunct Faculty

Timothy Collett, Senior Scientist, US Geological Survey

Gavin P. Hayes, NEIC Reseach Seismologist, US Geological Survey

Morgan Moschetti, Research Geophysicist, US Geological Survey

Ryan North, Principal Geophysicist, Olson Engineering

Nathaniel Putzig, Senior Scientist, Planetary Science Institute

Andreas Rueger, Chief Geophysicist, Digital Geo Specialists

# Humanities, Arts, and Social Sciences

## Degree Offered

- Master of Science in Natural Resources and Energy Policy (Non-Thesis)

## Certificates Offered

- Graduate Certificate in Natural Resources and Energy Policy

## Minors Offered

- Minor- A 12 credit-hour minor for graduate students pursuing degrees in other Mines academic units. Please contact either a Humanities, Arts, & Social Sciences faculty member with whom you are interested in working or the director of the NREP program. The Graduate Individual Minor must be approved by the student's graduate committee and by the NREP Director.

## Program Description

As the 21st century unfolds, we face major challenges in energy, natural resources, and the environment. The Division of Humanities, Arts, and Social Sciences offers a multidisciplinary graduate degree to help professionals solve these challenges: M.S.in Natural Resources and Energy Policy (NREP).

NREP provides engineers, social and physical scientists, and others interested in energy and natural resources (especially water) with a range of social science skills and knowledge. Open to new graduates as well as mid-career professionals, NREP teaches critical qualitative and quantitative skills to respond to domestic and global challenges related to energy, natural resources and resource management. The program is research and writing-intensive with a strong focus on verbal and written communication. The classes are small seminars that allow faculty to meet individual interests and backgrounds.

Through core courses electives from across campus, and internships, students acquire in-depth knowledge of political risk analysis and mitigation, community outreach and social responsibility, international development, and local and global policy making,. The degree targets the following jobs: analysts at energy and financial analytics companies; policy, government affairs, public affairs, risk management, community development, and similar positions in engineering companies; local, state, and federal government positions related to energy and resources; and non-profit organizations (advocacy, trade associations, etc.) working on energy, environment, or natural resources.

Drawing on Mines' international reputation, the faculty's extensive contacts, courses focused on problem-solving, and our well-placed Board of Advisors, graduates get jobs in industry, government, and non-governmental organizations. Students with undergraduate training in engineering may choose to work as engineers with a new awareness of social contexts, thus paving the way to new jobs and promotions, or choose a new career path such as in social responsibility, government relations, or advocacy. Those with social science or humanities training will find doors open to them in a wide range of energy and natural resources jobs.

NREP degree that requires 30 credit hours: 18 in the core and 12 in electives. Full-time students can complete the degree in 3 semesters (including summer).

## Combined Undergraduate/Graduate Degree Programs

Mines students may earn the master's degree as part of Mines' Combined Undergraduate/Graduate program. Students participating in the combined degree program may double count up to 6 semester hours of 400-level course work from their undergraduate course work.

Please note that Mines students interested in pursuing a Combined Undergraduate/Graduate program are encouraged to make an initial contact with the NREP Director after the first semester of their sophomore year for counseling on application procedures, admissions standards, and degree completion requirements.

See "Combined Undergraduate/Graduate Degree Programs" elsewhere in this bulletin for further details.

## Admission Requirements

The requirements for admission into Humanities, Arts, & Social Sciences Graduate Programs are as follows:

1. An undergraduate degree (engineering, social sciences, and others accepted) with a cumulative grade point average (GPA) at or above 3.0 (4.0 scale) or be a Mines undergraduate with a minimum GPA of 3.0 in the Humanities, Arts & Social Sciences course work.
2. The GRE is required for most applicants. GRE are waived for current MINES students and (with the NREP Director's approval) can be waived for those with 5+ years of relevant experience. GMAT and LSAT scores may be used in lieu of the GRE.
3. For students whose native language is not English, Mines requires a minimum TOEFL score of 79 internet-based test (iBT) or 550 paper-based test (PBT). Tests must have been taken within the past two years to be accepted. *If you have completed a university degree program in the United States or in an English speaking country within the previous two years, you do NOT have to submit TOEFL scores.*

## Program Requirements

## Master of Science in Natural Resources & Energy Policy (Non-Thesis)

The multidisciplinary NREP degree aims to train engineers and social scientists in the critical skills needed to respond to domestic and global challenges related to natural resources and energy issues in the 21st century. The program trains students in quantitative and qualitative methods as well as enhancing their skills to critically analyze natural resource, environment, and energy issues and to implement complex solutions in diverse social and political settings. Students engage in research- and writing-intensive assignments with a strong focus on verbal and written communication skills.

Graduates will gain in-depth knowledge of political risk analysis and mitigation, laws and regulations related to the extractive industries and the environment, principles of social responsibility, tools for community outreach and problem-solving, anti-corruption policies, and the politics and processes behind local, national, and global policymaking.

Designed for both early and mid-career professionals, the degree targets the following jobs: policy, government affairs, risk management, community development, social responsibility, and similar positions in energy, environment, and mining companies; local, state, and federal government positions related to energy and resources; and non-profit organizations (advocacy, trade associations, etc.) working on energy and natural resources issues.

NREP is a professional degree that requires 30 credit hours: 18 in the core and 12 in electives. Students are encouraged to pursue internships which may count toward elective credits. Transfer students may apply up to 6 credit hours for courses that meet our requirements.

**Required Courses**

| | | |
|---|---|---|
| HASS593 | NATURAL RESOURCES & ENERGY POLICY: THEORIES AND PRACTICE | 3.0 |
| PEGN530 | ENVIRONMENTAL LAW AND SUSTAINABILITY | 3.0 |
| HASS550 | POLITICAL RISK ASSESSMENT | 3.0 |
| MNGN571 | ENERGY, NATURAL RESOURCES, AND SOCIETY | 3.0 |
| ELECT | QUANTITATIVE METHODS ELECTIVE | 3.0 |
| Total Semester Hrs | | 15.0 |

Approved Quantitative Methods course list:

| | | |
|---|---|---|
| EBGN590 | ECONOMETRICS I | 3.0 |
| MATH530 | STATISTICAL METHODS I | 3.0 |
| MNGN565 | MINE RISK MANAGEMENT | 3.0 |
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |

- With the NREP Graduate Director’s approval, students may also take an online graduate-level course.

## Mines' Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any courses that count towards the graduate degree requirements as either "Required Coursework" or "Elective Coursework" may be used for the purposes of double counting at the discretion of the advisor (MS Non-Thesis) or thesis committee (MS Thesis or Ph.D.). These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit.

**Approved Electives by Areas of Interest**

4 courses (12 credit hours); at least 6 credit hours in HASS. Students may apply up to two 400-level courses (6 credit hours) in areas consistent with the degree and with the Graduate Director’s approval. Other electives may be approved on a case-by-case basis.

Students are encouraged to focus on one of the following areas of interest and/or to get a Minor in a related discipline, such as Environmental Engineering or Mining. Some courses have prerequisites or are primarily for engineers in those fields; students should check with the professor before taking the course.

## International Development and Global Issues

| | | |
|---|---|---|
| HASS535 | INTERNATIONAL DEVELOPMENT | 3.0 |
| HASS552 | CORRUPTION AND DEVELOPMENT | 3.0 |
| HASS558 | NATURAL RESOURCES AND DEVELOPMENT | 3.0 |
| HASS591 | ENERGY POLITICS | 3.0 |
| HASS592 | ENERGY AND SECURITY POLICY | 3.0 |
| HASS552 | CORRUPTION AND DEVELOPMENT | 3.0 |

## Energy and Environmental Studies

| | | |
|---|---|---|
| HASS521 | ENVIRONMENTAL PHILOSOPHY | 3.0 |
| HASS525 | ENVIRONMENTAL COMMUNICATION | 3.0 |
| HASS587 | ENVIRONMENTAL POLITICS AND POLICY | 3.0 |
| HASS588 | GLOBAL WATER POLITICS AND POLICY | 3.0 |
| HASS591 | ENERGY POLITICS | 3.0 |
| HASS592 | ENERGY AND SECURITY POLICY | 3.0 |
| CEEN573 | RECLAMATION OF DISTURBED LANDS | 3.0 |
| CEEN574 | SOLID WASTE MINIMIZATION AND RECYCLING | 3.0 |
| CEEN575 | HAZARDOUS WASTE SITE REMEDIATION | 3.0 |
| CEEN576 | POLLUTION PREVENTION: FUNDAMENTALS AND PRACTICE | 3.0 |
| CEEN595 | ANALYSIS OF ENVIRONMENTAL IMPACT | 3.0 |
| EBGN570 | ENVIRONMENTAL ECONOMICS | 3.0 |

## Mining

| | | |
|---|---|---|
| CEEN556 | MINING AND THE ENVIRONMENT | 3.0 |
| CEEN573 | RECLAMATION OF DISTURBED LANDS | 3.0 |
| MNGN501 | REGULATORY MINING LAWS AND CONTRACTS | 3.0 |
| MNGN503 | MINING TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT | 3.0 |
| MNGN510 | FUNDAMENTALS OF MINING AND MINERAL RESOURCE DEVELOPMENT | 3.0 |
| MNGN540 | CLEAN COAL TECHNOLOGY | 3.0 |

## Business, Economics, and Energy Analytics

| | | |
|---|---|---|
| EBGN509 | MATHEMATICAL ECONOMICS | 3.0 |
| EBGN510 | NATURAL RESOURCE ECONOMICS | 3.0 |
| EBGN530 | ECONOMICS OF INTERNATIONAL ENERGY MARKETS | 3.0 |
| EBGN594 | TIME-SERIES ECONOMETRICS | 3.0 |
| EBGN632 | PRIMARY FUELS | 3.0 |
| GEOL514 | BUSINESS OF ECONOMIC GEOLOGY | 3.0 |
| MATH530 | STATISTICAL METHODS I | 3.0 |

Courses approved for Quantitative Methods may also be taken as electives

## Program Requirements

## Graduate Certificate in Natural Resources and Energy Policy

Designed to be completed in a single semester, or over two semesters for part-time students, the Certificate in Natural Resources & Energy Policy (NREP) is a 12 credit-hour program affiliated with the MS in NREP.

To earn the certificate, students must take four of the five required courses for the Master's program:

| | | |
|---|---|---|
| HASS593 | NATURAL RESOURCES & ENERGY POLICY: THEORIES AND PRACTICE | 3.0 |
| PEGN530 | ENVIRONMENTAL LAW AND SUSTAINABILITY | 3.0 |
| MNGN590 | MECHANICAL EXCAVATION IN MINING | 3.0 |
| HASS550 | POLITICAL RISK ASSESSMENT | 3.0 |
| QUANT | QUANTITATIVE METHODS ELECTIVE | |

Approved Quantitative Methods list:

| | | |
|---|---|---|
| EBGN590 | ECONOMETRICS I | 3.0 |
| MATH530 | STATISTICAL METHODS I | 3.0 |
| MNGN565 | MINE RISK MANAGEMENT | 3.0 |
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |

## Courses

**HASS521. ENVIRONMENTAL PHILOSOPHY AND POLICY. 3.0 Semester Hrs.**

Equivalent with LAIS521,

Analyzes environmental ethics and philosophy including the relation of philosophical perspectives to policy decision making. Critically examines often unstated ethical and/or philosophical assumptions about the environment and how these may complicate and occasionally undermine productive policies. Policies that may be considered include environmental protection, economic development, and energy production and use. 3 hours seminar; 3 semester hours.

**HASS523. ADVANCED SCIENCE COMMUNICATION. 3.0 Semester Hrs.**

Equivalent with LAIS523,

This course will examine historical and contemporary case studies in which science communication (or miscommunication) played key roles in shaping policy outcomes and/or public perceptions. Examples of cases might include the recent controversies over hacked climate science emails, nuclear power plant siting controversies, or discussions of ethics in classic environmental cases, such as the Dioxin pollution case. Students will study, analyze, and write about science communication and policy theories related to scientific uncertainty; the role of the scientist as communicator; and media ethics. Students will also be exposed to a number of strategies for managing their encounters with the media, as well as tools for assessing their communication responsibilities and capacities. 3 hours seminar; 3 semester hours.

**HASS525. ENVIRONMENTAL COMMUNICATION. 3.0 Semester Hrs.**

Equivalent with LAIS525,

(I, II, S) This course explores the ways that messages about the environment and environmentalism are communicated in the mass media, fine arts, and popular culture. The course will introduce students to key readings in environmental communication, media studies, and cultural studies in order to understand the many ways in which the images, messages, and politics of environmentalism and the natural world are constructed and contested by diverse audiences. Students will critically analyze their roles as science and/or technology communicators in the context of environmental issues, and will apply their skills to creating communications projects for diverse audiences. 3 lecture hours, 3 semester hours.

**HASS535. INTERNATIONAL DEVELOPMENT. 3.0 Semester Hrs.**

Equivalent with LAIS535,

(I, II, S) Explores the political economy of current and recent-historical development strategies, models, efforts, and issues in various world regions. The class will focus on Africa, Asia, Eurasia, Latin America, or the Middle East, depending on the semester. Development is understood to be a nonlinear, complex set of processes involving political, economic, social, cultural, and environmental factors whose ultimate goal is to improve the quality of life for individuals. Students will explore the roles of governments, companies, organizations, and individuals. Exact topics to be covered will vary with current events and the specific region; topics might include income inequality, the role of national and private energy companies, the impact of globalization, the role of development aid, and concepts of good governance. Students may take the course up to three times, covering different regions. 3 hours lecture; 3 semester hours.

**HASS541. AFRICAN DEVELOPMENT. 3.0 Semester Hrs.**

Equivalent with LAIS541,

Provides a broad overview of the political economy of Africa. Its goal is to give students an understanding of the possibilities of African development and the impediments that currently block its economic growth. Despite substantial natural resources, mineral reserves, and human capital, most African countries remain mired in poverty. The struggles that have arisen on the continent have fostered thinking about the curse of natural resources where countries with oil or diamonds are beset with political instability and warfare. Readings give first an introduction to the continent followed by a focus on the specific issues that confront African development today. 3 hours lecture and discussion; 3 semester hours.

**HASS542. NATURAL RESOURCES AND WAR IN AFRICA. 3.0 Semester Hrs.**

Equivalent with LAIS542,

Examines the relationship between natural resources and wars in Africa. It begins by discussing the complexity of Africa with its several many languages, peoples, and geographic distinctions. Among the most vexing challenges for Africa is the fact that the continent possesses such wealth and yet still struggles with endemic warfare, which is hypothetically caused by greed and competition over resource rents. Readings are multidisciplinary and draw from policy studies, economics, and political science. Students will acquire an understanding of different theoretical approaches from the social sciences to explain the relationship between abundant natural resources and war in Africa. The course helps students apply the different theories to specific cases and productive sectors. 3 hours lecture and discussion; 3 semester hours.

**HASS545. INTERNATIONAL POLITICAL ECONOMY. 3.0 Semester Hrs.**

Equivalent with LAIS545,

Introduces students to the field of International Political Economy (IPE) . IPE scholars examine the intersection between economics and politics, with a focus on interactions between states, organizations, and individuals around the world. Students will become familiar with the three main schools of thought on IPE: Realism (mercantilism), Liberalism, and Historical Structuralism (including Marxism and feminism) and will evaluate substantive issues such as the role of international organizations (the World Trade Organization, the World Bank, and the International Monetary Fund), the monetary and trading systems, regional development, international development, foreign aid, debt crises, multinational corporations, and globalization. 3 hours seminar; 3 semester hours.

**HASS550. POLITICAL RISK ASSESSMENT. 3.0 Semester Hrs.**
Equivalent with LAIS550,
Uses social science analytical tools and readings as well as indices prepared by organizations, such as the World Bank and the International Monetary Fund, to create assessments of the political, social, economic, environmental and security risks that multinational corporations may face as they expand operations around the world. Students will develop detailed political risk reports for specific countries that teams collectively select. Prerequisite: HASS 545 and IPE Minor. 3 hours seminar; 3 semester hours.

**HASS552. CORRUPTION AND DEVELOPMENT. 3.0 Semester Hrs.**
Equivalent with LAIS552,
Addresses the problem of corruption and its impact on development. Readings are multidisciplinary and include policy studies, economics, and political science. Students will acquire an understanding of what constitutes corruption, how it negatively affects development, and what they, as engineers in a variety of professional circumstances, might do in circumstances in which bribe paying or taking might occur. 3 hours lecture and discussion; 3 semester hours.

**HASS558. NATURAL RESOURCES AND DEVELOPMENT. 3.0 Semester Hrs.**
Equivalent with LAIS558,
Examines the relationship between natural resources and development. It begins by discussing theories of development and how those theories account for specific choices among resource abundant countries. From the theoretical readings, students examine sector specific topics in particular cases. These subjects include oil and natural gas in African and Central Asian countries; hard rock mining in West Africa and East Asia; gemstone mining in Southern and West Africa; contracting in the extractive industries; and corporate social responsibility. Readings are multidisciplinary and draw from policy studies, economics, and political science to provide students an understanding of different theoretical approaches from the social sciences to explain the relationship between abundant natural resources and development. 3 hours lecture and discussion; 3 semester hours.

**HASS560. GLOBAL GEOPOLITICS. 3.0 Semester Hrs.**
Equivalent with LAIS560,
Examines geopolitical theories and how they help us explain and understand contemporary developments in the world. Empirical evidence from case studies help students develop a deeper understanding of the interconnections between the political, economic, social, cultural and geographic dimensions of governmental policies and corporate decisions. Prerequisites: any two IPE courses at the 300-level, or one IPE course at the 400 level. 3 hours lecture and discussion; 3 semester hours.

**HASS565. SCIENCE, TECHNOLOGY, AND SOCIETY. 3.0 Semester Hrs.**
Equivalent with LAIS565,
Provides an introduction to foundational concepts, themes, and questions developed within the interdisciplinary field of science and technology studies (STS). Readings address anthropological understandings of laboratory practice, sociological perspectives on the settling of techno-scientific controversies, historical insights on the development of scientific institutions, philosophical stances on the interactions between technology and humans, and relationships between science and democracy. Students complete several writing assignments, present material from readings and research, and help to facilitate discussion. 3 hours lecture and discussion; 3 semester hours.

**HASS584. US WATER POLITICS AND POLICY. 3.0 Semester Hrs.**
(I) The story of water in the American West is one of engineering and applied science inextricably intertwined with a "Gordian knot" of law and policy, changing social and cultural values, and increasingly unpredictable hydrology. This course will familiarize students with the complexities of contemporary water governance, using the Colorado River system as its central case study. The Colorado River makes for an excellent point of departure because it is one of the most dammed, diverted, legislated, litigated, and loved rivers in the world and because we literally use it up; the river has seldom reached the sea since the 1960s. Indeed, the challenges that face the Colorado River's 40 million stakeholders today have less to do with applying law and engineering to developing water resources, and much more to do with figuring out how to share an over-appropriated resource while mitigating the social and ecological consequences of past choices. Our primary goal in the course will be to learn concepts of adaptive governance that provide a constructive and framework for analyzing and addressing such challenges. 3 hours lecture; 3 semester hours.

**HASS586. SCIENCE AND TECHNOLOGY POLICY. 3.0 Semester Hrs.**
Equivalent with LAIS586,
Examines current issues relating to science and technology policy in the United States and, as appropriate, in other countries. 3 hours lecture and discussion; 3 semester hours.

**HASS587. ENVIRONMENTAL POLITICS AND POLICY. 3.0 Semester Hrs.**
Equivalent with LAIS587,
Explores environmental policies and the political and governmental processes that produce them. Group discussion and independent research on specific environmental issues. Primary but not exclusive focus on the U.S. 3 hours lecture and discussion; 3 semester hours.

**HASS588. GLOBAL WATER POLITICS AND POLICY. 3.0 Semester Hrs.**
Equivalent with LAIS588,
(II) This interdisciplinary seminar course analyzes how droughts, floods, water management, global trading system, and climate change affect the hydrological and food systems that are critically important for economic prosperity and political stability. It addresses water policy at scales that range from community level to global governance regimes. It uses relevant analytical perspectives of, for example, psychology, political economy, development studies, and institutional approaches in economic geography to help students understand how certain transboundary water conflicts have emerged, their national and regional implications, and policies and institutions that can be used to resolve them. 3 hours lecture; 3 semester hours.

**HASS590. ENERGY AND SOCIETY. 3.0 Semester Hrs.**
Equivalent with LAIS590,
(II) The course begins with a brief introduction to global energy production and conservation, focusing on particular case studies that highlight the relationship among energy, society, and community in different contexts. The course examines energy successes and failures wherein communities, governments, and/or energy companies come together to promote socially just and economically viable forms of energy production/conservation. The course also explores conflicts driven by energy development. These case studies are supplemented by the expertise of guest speakers from industry, government, NGOs, and elsewhere. Areas of focus include questioning the forward momentum of energy production, its social and environmental impact, including how it distributes power, resources and risks across different social groups and communities. 3 hours seminar; 3 semester hours.

**HASS591. ENERGY POLITICS. 3.0 Semester Hrs.**
(I) We will use political science approaches, theories, and methods to investigate the global, regional, state, and local politics of renewable and non-renewable energy, spanning all uses: transportation, heating and cooling, and electricity. We will look at the politics behind energy in a subset of countries to be chosen by the class, such as China, Brazil, India, Austria, Spain, Venezuela, and Germany. We will then focus on energy in Colorado (and possibly a few other US states), conducting primary research on the stakeholders and the relevant political outcomes for non-renewables and renewables, making comparisons between the two groups. We will work with energy companies, non-governmental organizations, university and research entities, government representatives, and local activists. 3 lecture hours, 3 semester hours.

**HASS592. ENERGY AND SECURITY POLICY. 3.0 Semester Hrs.**
(II) Energy and Security Policy is a graduate course that applies a social science lens to understanding the intersections between national and international security concerns and energy. In this course, we will examine these intersections through a case study approach that includes directed readings, such as books and peer-reviewed journal articles, that incorporate student-led discussions and research projects. By exploring various energy security scenarios, such as restricted access to oil and gas, graduate students will gain a comprehensive understanding of the energy-security nexus and the role governments and policies play in enhancing or limiting security. 3 hours lecture, 3 semester hours.

**HASS593. NATURAL RESOURCES & ENERGY POLICY: THEORIES AND PRACTICE. 3.0 Semester Hrs.**
(I) This course introduces students to the policy-making process, drawing on a variety of theoretical approaches, geographic locations (within the US and in other countries), and resources and energy issues. Coordinated by the NREP Graduate Director, speakers will be from HASS, Economics and Business, Petroleum Engineering, Mining, and other departments with policy expertise, as well as from others who influence and create public and private policy. In the second half of the course, students will conduct original research projects that focus on natural resources and energy, applying theoretical frameworks they have learned from the speakers. 3 lecture hours, 3 semester hours.

**HASS598. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**HASS599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**HASS601. ACADEMIC PUBLISHING. 2-3 Semester Hr.**
Equivalent with LAIS601,
Students will finish this course with increased knowledge of general and discipline - specific writing conversations as well as the ability to use that knowledge in publishing portions of theses or dissertations. Beyond the research article, students will also have the opportunity to learn more about genres such as conference abstracts, conference presentations, literature reviews, and research funding proposals. Prerequisite: Must have completed one full year (or equivalent) of graduate school course work. Variable credit: 2 or 3 semester hours.

**HASS698. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**HASS699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**HASS707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
Equivalent with LAIS707,
(I, II, S) GRADUATE THESIS/DISSERTATION RESEARCH CREDIT Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

**LICM501. PROFESSIONAL ORAL COMMUNICATION. 1.0 Semester Hr.**
A five-week course which teaches the fundamentals of effectively preparing and presenting messages. "Hands-on" course emphasizing short (5- and 10-minute) weekly presentations made in small groups to simulate professional and corporate communications. Students are encouraged to make formal presentations which relate to their academic or professional fields. Extensive instruction in the use of visuals. Presentations are rehearsed in class two days prior to the formal presentations, all of which are video-taped and carefully evaluated. 1 hour lecture/lab; 1 semester hour.

## Professors

Hussein A. Amery, Division Director

Elizabeth Van Wie Davis

Jon A. Leydens

Kenneth Osgood,

## Associate Professors

Tina L. Gianquitto

Kathleen J. Hancock, NREP Graduate Program Director

John R. Heilbrunn

James D. Straker

## Assistant Professors

Adrianne Kroepsch

Qin Zhu

## Teaching Professors

Jonathan Cullison

Paula A. Farca

Cortney Holles

Robert Klimek

Toni Lefton, Director, University Honors and Scholars Programs

Sandy Woodson, Undergraduate Advisor

## Teaching Associate Professors

Melanie Brandt , Associate Director McBride Program

Maggie Greenwood

Seth Tucker

Eliza Buhrer

Joseph Horan, Associate Division Director

Derrick Hudson

Shannon Davies Mancus

Rose Pass

## Teaching Assistant Professor

Rachel Osgood

## Professors Emeriti

W. John Cieslewicz

T. Graham Hereford

Barbara M. Olds

Eul-Soo Pang

Anton G. Pegis

Thomas Philipose, University Emeritus Professor

Arthur B. Sacks

## Associate Professors Emeriti

Betty J. Cannon

Kathleen H. Ochs

Laura J. Pang

Karen B. Wiley

## Teaching Professor Emeriti

James Jesudason

# Mechanical Engineering

## Degrees Offered

- Master of Science (Mechanical Engineering)
- Doctor of Philosophy (Mechanical Engineering)

## Program Overview

The Mechanical Engineering Department offers the Master of Science and Doctor of Philosophy degrees in Mechanical Engineering. The program demands academic rigor and depth yet also addresses real-world engineering problems. The department has four broad divisions of research activity that stem from core fields in Mechanical Engineering: (1) Biomechanics, (2) Thermal-Fluid Systems, (3) Solid Mechanics, Materials, and Manufacturing, and (4) Robotics and Automation. In many cases, individual research projects encompass more than one research area and elements from other disciplines.

***Biomechanics*** focuses on the application of engineering principles to the musculoskeletal system and other connective tissues. Research activities include experimental, computational, and theoretical approaches with applications in the areas of rehabilitation engineering, computer-assisted surgery and medical robotics, patient-specific biomechanical modeling, intelligent prosthetics and implants, and bioinstrumentation. The Biomechanics group has strong research ties with other campus departments, the local medical community, and industry partners.

***Robotics and Automation*** merges research from multiple areas of science and engineering. Topics include the design of robotic and automation system hardware and software, particularly for tasks that require some level of autonomy, intelligence, self-prognostics and decision making. Such capabilities are built upon integrated mechatronic systems that enable pro-active system responses to its environment and current state. These capabilities are applied in applications such as advanced robotics and manufacturing systems. Research in this division explores the science underlying the design process, implementation of mechanical and control systems to enable autonomy, and innovative computational analysis for automation, intelligence, and systems optimization.

***Solid Mechanics, Materials, and Manufacturing*** develops novel computational and experimental solutions for problems in the mechanical behavior of advanced materials. Research in the division spans length scales from nanometer to kilometer, and includes investigations of microstructural effects on mechanical behavior, nanomechanics, granular mechanics, and continuum mechanics. Material-behavior models span length scales from the nano- and micro-scale, to the meso- and macro-scale. Much of the research is computational in nature using advanced computational methods such as molecular dynamics, finite-element, boundary-element and discrete-element methods. Strong ties exist between this group and the campus communities of applied mathematics, chemical engineering, materials science, metallurgy, and physics.

***Thermal Fluid Systems*** incorporates a wide array of multidisciplinary applications such as advanced energy conversion and storage, multi-phase fluid flows, materials processing, combustion, alternative fuels, and renewable energy. Research in thermal-fluid systems integrates the disciplines of thermodynamics, heat transfer, fluid mechanics, transport phenomena, chemical engineering, and materials science towards solving problems and making advances through experiments and computational modeling in the broad areas of energy conversion, fluid mechanics, and thermal transport. Research projects in this area specialize in some aspect of mechanical engineering but often have a strong interdisciplinary component in related fields such as Materials Science and Chemical Engineering.

## Program Details

The Mechanical Engineering Department offers the degrees Master of Science and Doctor of Philosophy in Mechanical Engineering. The master's program is designed to prepare candidates for careers in industry or government or for further study at the PhD level; both thesis and non-thesis options are available. The PhD degree program is sufficiently flexible to prepare candidates for careers in industry, government, or academia. The following information provides details on these degrees.

## Mines' Combined Undergraduate / Graduate Degree Program

The ME Department will allow students enrolled in the combined BS/MS-Mechanical Engineering Non-Thesis program to double count up to 6 course credits from their undergraduate ME degree requirements. This program enables students to begin graduate coursework while still finishing their undergraduate degree requirements. Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits of MEGN 400- or 500-level courses, which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their non-thesis graduate program. ME majors may double count any 400-level or above course on the approved Mechanical Engineering Elective list provided in the Undergraduate Catalog. Non-ME majors may double count any 400-level or above course on the approved Mechanical Engineering Elective list and any MEGN 400-level or above course. These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit.

## Prerequisites

*Requirements for Admissions:* The minimum requirements for admission into the MS and PhD degrees in Mechanical Engineering are:

- a baccalaureate degree in engineering, computer science, a physical science, or mathematics with a minimum grade-point average of 3.0;
- Graduate Record Examination (Quantitative Reasoning) section score of 160 or higher. Applicants from an engineering program at CSM are not required to submit GRE scores;
- TOEFL score of 79 or higher (or 550 paper-based or 213 computer-based) for applicants whose native language is not English.

## Program Requirements

*Admitted Students:* The Mechanical Engineering graduate admissions committee may require that an admitted student complete undergraduate remedial coursework to overcome technical deficiencies. Such coursework may not count toward the graduate degree. The committee will decide whether to recommend regular or provisional admission, and may ask the applicant to come to campus for an interview.

*Transfer Courses:* Graduate-level courses taken at other universities for which a grade equivalent to a "B" or better was received will be considered for transfer credit into the Mechanical Engineering Department. Approval from the Advisor and/or Thesis Committee and

ME Department Head will be required as appropriate. Transfer credits must not have been used as credit toward a Bachelor degree. For the MS degree, no more than nine credits may transfer. For the PhD degree, up to 24 credit hours may be transferred. In lieu of transfer credit for individual courses, students who enter the PhD program with a thesis-based master's degree from another institution may transfer up to 36 hours in recognition of the course work and research completed for that degree.

*400-level Courses:* As stipulated by the CSM Graduate School, students may apply toward graduate degree requirements a maximum of nine (9.0) semester hours of department-approved 400-level course work.

## Master of Science Degree Requirements

The MS degree in Mechanical Engineering requires 30 credit hours. Requirements for the MS thesis option are 24 credit hours of coursework and 6 credit hours of thesis research. The MS non-thesis option requires 30 credit hours of coursework. *All MS students must complete nine credit hours of course work within one research division by selecting three courses listed under the Research Division Courses.*

*Advisor and Thesis Committee:* Students must have an Advisor from the Mechanical Engineering Department Faculty to direct and monitor their academic plan, research, and independent studies. The MS graduate Thesis Committee must have at least three members, two of whom must be permanent faculty in the Mechanical Engineering Department.

### MS Thesis Degree

| | | |
|---|---|---|
| MEGN502 | ADVANCED ENGINEERING ANALYSIS | 3.0 |
| MEGN503 | GRADUATE SEMINAR Enrollment required every fall and spring semester | 0.0 |
| RESEARCH CORE | Courses from one Research Division List | 9.0 |
| TECHNICAL ELECTIVES | Technical Electives Courses approved by Advisor/Thesis Committee. | 9.0 |
| ME ELECTIVES | Any 400-level or above MEGN, AMFG, or FEGN course | 3.0 |
| MEGN707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 6.0 |
| Total Semester Hrs | | 30.0 |

*Thesis Defense*: At the conclusion of the MS (Thesis Option), the student will be required to make a formal presentation and defense of her/his thesis research to his Advisor and Thesis Committee.

### MS Non-Thesis Degree

| | | |
|---|---|---|
| MEGN502 | ADVANCED ENGINEERING ANALYSIS | 3.0 |
| RESEARCH CORE | Course from one Research Division List | 9.0 |
| TECHNICAL ELECTIVES | Technical Electives Courses must be approved by Advisor. | 9.0 |
| ME ELECTIVES | Any 400-level or above MEGN, AMFG, or FEGN course | 9.0 |
| Total Semester Hrs | | 30.0 |

*Time Limit:* As stipulated by the Mines Graduate School, a candidate for a Masters degree must complete all requirements for the degree within five years of the date of admission into the degree program.

## Doctor of Philosophy Degree Requirements

The PhD degree in Mechanical Engineering requires 72 credit hours of course work and research credits. A minimum of 36 credit hours of course work and 30 credit hours of research credits must be completed. A minimum of 12 of the 36 credit hours of required coursework must be taken at Colorado School of Mines. *All students must complete nine credit hours of course work within one research area by selecting 3 courses listed under the Research Division Courses.*

| | | |
|---|---|---|
| MEGN502 | ADVANCED ENGINEERING ANALYSIS | 3.0 |
| MEGN503 | GRADUATE SEMINAR Enrollment required every fall and spring semester | 0.0 |
| RESEARCH CORE | Courses from one Research Division List | 9.0 |
| TECHNICAL ELECTIVES | Technical Electives Must be approved by the Advisor/Thesis Committee. | 24.0 |
| MEGN707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 30.0 |
| TOTAL CREDITS | Remaining credits can come from Research and/or Technical Electives | 72.0 |

*Timeline and Milestones:* PhD students must make adequate progress and reach appropriate milestones toward their degree by working with their faculty Advisor and thesis committee. The ME faculty has adopted a PhD timeline that outlines milestones students should reach on a semester-by-semester basis. Each milestone is listed here with more detailed explanations given below:

| MILESTONE | TIMELINE |
|---|---|
| Select a permanent advisor | Second semester |
| Complete the PhD qualifying examination | Third semester |
| Establish a dissertation committee and present research proposal | Fourth semester |
| Complete all core curriculum course requirements | Fourth semester |
| Submit Degree Audit and Admission to Candidacy forms | Fourth semester |
| Present a preliminary defense | 12 months before dissertation defense |
| Present a dissertation defense | |

*Advisor and Thesis Committee:* Students must have an Advisor from the Mechanical Engineering Department Faculty to direct and monitor their academic plan, research, and independent studies. The PhD graduate Thesis Committee must have at least four members; at least two members must be permanent faculty in the Mechanical Engineering Department, and at least one member must be from outside the department. This outside member must chair the committee. Students who choose to have a minor program must select a representative from the minor areas of study to serve on the Thesis Committee.

*Qualifying Exam:* Students enrolled in the Mechanical Engineering PhD program will be required to pass a Qualifying Exam. The PhD qualifying exam will be administered at a specific date during every semester by each research division independently. Each research division will appoint a Qualifying Exam chair, who oversees the process and ensures that the exam is administered fairly. Students must take the exam by no later than the end of their third semester in the Mechanical Engineering PhD program. If the student fails the exam on their first attempt, they must retake the exam in the following semester with a maximum of two attempts to pass. One-semester extensions may be granted upon request to students who are enrolled as part-time or with non-ME backgrounds.

The Qualifying Exam assesses some attributes expected of a successful PhD student, including:

- ability to review, synthesize and apply fundamental concepts;
- creative and technical potential of the student to solve open-ended and challenging problems;
- technical communication skills.

A written exam not to exceed 4.5 hours will be administered which will be divided into no more than five topical areas related to the research division, with topics announced in advance of the exam. Research divisions will choose topical areas related to foundational undergraduate material and material in the core graduate courses required by that research division. Students, in consultation with faculty advisors, will choose three topical areas.

Students, with a satisfactory performance on the written exam, will participate in an oral exam not to exceed two hours. The oral exam will be conducted by the qualifying exam committee and the student's advisor. The research division will specify the format of the exam in advance of the exam.

Students with satisfactory performance on the written exam will be given two weeks to write a two-page critical review of a journal paper. Students will select one paper from an approved list of journal papers provided by the Qualifying Exam Chair. At least two weeks before the written exam, the Chair will solicit research topics for seeding the journal paper list from students taking the qualifier and their advisors.

Exam results of Pass, Conditional Pass or Fail will be provided to the student in a timely manner by the exam committee. A Conditional Pass will require the student to take a remedial plan.

*Research Proposal*: After passing the Qualifying Examination, the PhD student will prepare a written Research Proposal for the Dissertation and present it formally to the Dissertation Committee, which is selected by the student and the student's advisor and approved by the Department Head. A written Research Proposal document consisting of no more than 10 pages will be provided to the Committee in advance of the presentation with the expectation of achieving the following:

- Demonstrate a thorough familiarity with the background and motivation of the research problem being undertaken as embodied by a review of the relevant literature;
- Enumerate specific aims and/or hypotheses;
- Identify preliminary techniques, materials, and specific measurements for the proposed research project;
- Explain clearly the scientific merit ("value added") of the proposed work;
- Provide a general idea of the timeline for the research program;
- Specify potential publications and presentations that may arise from the work.

The student and the advisor must convene a meeting of the full Dissertation Committee in which the student gives an oral summary of their written proposal in a 30-45 minute presentation. This Research Proposal gives the Committee an early chance to discuss the work and to help the student more clearly define the work and identify the salient aspects. For most students, Research Proposal presentation will happen the semester after successfully passing the qualifier. The research proposal must be completed before admission to candidacy. If the qualifier is passed after the fourth semester, admission to candidacy may be granted prior to the research proposal with ME Graduate Curriculum Committee approval.

*Degree Audit and Admission to Candidacy:* PhD students must complete the Degree Audit form (http://gradschool.mines.edu/Degree-Audit/) by the posted deadlines and the Admission to Candidacy form (http://gradschool.mines.edu/Admission-to-Candidacy-form/) by the first day of classes of the semester in which they want to be considered eligible for reduced registration.

Additionally, full-time PhD students must complete the following requirements within the first two calendar years after enrolling into the PhD program:

- have a Thesis Committee appointment form on file in the Graduate Office;
- complete all prerequisite and core curriculum course requirements;
- demonstrate adequate preparation for, and satisfactory ability to conduct doctoral research; and
- be admitted into full candidacy for the degree.

*Preliminary Defense:* Prior to the final Dissertation Defense, the PhD student will make an oral presentation to the student's Committee to summarize research accomplishments and remaining goals and work plan. This meeting serves as a final check to assess if the student's progress is on schedule for graduation. This meeting should present a preliminary document that will likely evolve and expand into the Dissertation. The preliminary document should include basic literature review, methodologies used, results to date, and an estimated timeline for remaining work. The student must give no more than a 45-minute presentation that summarizes the work already accomplished, including their relevant publication(s) and a proposed plan of the work needed to culminate in a formal defense and graduation. The Committee will provide feedback and, as necessary, revisions to the proposed work plan such that its completion should lead to a successful Dissertation Defense and publication record in a realistic time frame. The time period between the Research Proposal and the Preliminary Defense can span a few years, but the Preliminary Defense should take place 12 months and no less than 6 months prior to the date of Dissertation Defense.

*Required Number of Publications and Presentations:* The required and recommended journal publications for PhD students prior to graduation are listed below. Students wanting to defend before meeting these requirements must submit a one-page petition with a reasonable explanation to the ME Graduate Curriculum Committee.

Journal publications **-** *Required:* Minimum of one first-author paper accepted or published (DOI is required) in a peer-reviewed journal (recognized as high quality in the research field), before Dissertation Defense. *Recommended:* Three or more first-author papers accepted or published in peer-reviewed journals. More than three first author journal publications are recommended for students interested in academic positions.

Presentations **-** *Required:* Minimum of one research presentation (poster or podium) at an external technical conference before the Dissertation Defense. Minimum of three presentations in the research division's MEGN 503 or equivalent (such as campus-wide graduate student research conference, research sponsor meetings, or additional conference presentations) during PhD program. *Recommended:* Two or more conference presentations (poster or podium), before the Dissertation Defense in which the student is the first author on these presentations. Numerous conference presentations are strongly encouraged to establish a reputation amongst researchers in a field for students interested in academic positions.

*Thesis Defense:* At the conclusion of the student's PhD program, the student will be required to make a formal presentation and defense of her/his thesis research. A student must "pass" this defense to earn a PhD degree. The Dissertation document should be submitted to the Dissertation Committee at least 10 days prior to the Defense. The Committee will perform a post-presentation review of the Dissertation, technical contributions, and publications with the student. The Committee may request revisions to the Dissertation and additional work that requires subsequent review by the advisor and or the Committee.

*Unsatisfactory Progress:* To ensure that a student receives proper feedback if progress toward the Preliminary Defense or the Dissertation Defense is not satisfactory, the Advisor must provide the student and the Committee a brief, written progress evaluation. If the student's progress is unsatisfactory such that the Advisor gives them a PRU grade for research credits, the student will go on academic probation as outlined in the Graduate Bulletin.

*Time Limit:* As stipulated by the Mines Graduate School, a candidate for a doctoral degree must complete all requirements for the degree within nine years of the date of admission into the degree program.

**RESEARCH DIVISION COURSES**

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|---|---|---|
| **BIOMECHANIC COURSES** | | |
| MEGN514 | CONTINUUM MECHANICS | |
| MEGN531 | PROSTHETIC AND IMPLANT ENGINEERING | |
| MEGN532 | EXPERIMENTAL METHODS IN BIOMECHANICS | |
| MEGN535 | MODELING AND SIMULATION OF HUMAN MOVEMENT | |
| MEGN536 | COMPUTATIONAL BIOMECHANICS | |
| MEGN540 | MECHATRONICS | |
| **ROBOTICS AND AUTOMATION** | | |
| MEGN540 | MECHATRONICS | |
| MEGN544 | ROBOT MECHANICS: KINEMATICS, DYNAMICS, AND CONTROL | |
| MEGN545 | ADVANCED ROBOT CONTROL | |
| MEGN587 | NONLINEAR OPTIMIZATION | |
| MEGN588 | INTEGER OPTIMIZATION | |
| **SOLID MECHANICS, MATERIALS, AND MANUFACTURING** | | |
| MEGN511 | FATIGUE AND FRACTURE | |
| MEGN512 | ADVANCED ENGINEERING VIBRATION | |
| MEGN514 | CONTINUUM MECHANICS | |
| MEGN515 | COMPUTATIONAL MECHANICS | |
| MEGN517 | INELASTIC CONSTITUTIVE RELATIONS | |
| MEGN584 | MODELING MATERIALS PROCESSING | 3.0 |
| MEGN5XX | MICROMECHANICS/HOMOGENIZATION | |
| **THERMAL-FLUID SYSTEMS** | | |
| MEGN551 | ADVANCED FLUID MECHANICS | |
| MEGN552 | VISCOUS FLOW AND BOUNDARY LAYERS | |
| MEGN561 | ADVANCED ENGINEERING THERMODYNAMICS | |
| MEGN566 | COMBUSTION | |
| MEGN571 | ADVANCED HEAT TRANSFER | |

## Courses

**MEGN501. ADVANCED ENGINEERING MEASUREMENTS. 3.0 Semester Hrs.**

Equivalent with EGGN501,
Introduction to the fundamentals of measurements within the context of engineering systems. Topics that are covered include: errors and error analysis, modeling of measurement systems, basic electronics, noise and noise reduction, and data acquisition systems. Prerequisite: EGGN250, EENG281 or equivalent, and MATH201 or equivalent, Graduate student status.

**MEGN502. ADVANCED ENGINEERING ANALYSIS. 3.0 Semester Hrs.**

(I) Introduce advanced mathematical and numerical methods used to solve engineering problems. Analytic methods include series solutions, special functions, Sturm-Liouville theory, separation of variables, and integral transforms. Numerical methods for initial and boundary value problems include boundary, domain, and mixed methods, finite difference approaches for elliptic, parabolic, and hyperbolic equations, Crank-Nicolson methods, and strategies for nonlinear problems. The approaches are applied to solve typical engineering problems. Prerequisite: This is an introductory graduate class. The student must have a solid understanding of linear algebra, calculus, ordinary differential equations, and Fourier theory. 3 hours lecture.

**MEGN503. GRADUATE SEMINAR. 0.0 Semester Hrs.**

(I, II) This is a seminar forum for graduate students to present their research projects, critique others? presentations, understand the breadth of engineering projects both within their specialty area and across the Division, hear from leaders of industry about contemporary engineering as well as socio-economical and marketing issues facing today?s competitive global environment. In order to improve communication skills, each student is required to present a seminar in this course before his/her graduation from the Mechanical Engineering graduate program. Prerequisite: Graduate standing. 1 hour per week; 0 semester hours. Course is repeatable, but no coursework credit is awarded.

**MEGN510. SOLID MECHANICS OF MATERIALS. 3.0 Semester Hrs.**

(II) Introduction to the algebra of vectors and tensors; coordinate transformations; general theories of stress and strain; principal stresses and strains; octahedral stresses; Hooke?s Law introduction to the mathematical theory of elasticity and to energy methods; failure theories for yield and fracture. Prerequisite: CEEN311 or equivalent, MATH225 or equivalent. 3 hours lecture; 3 semester hours.

**MEGN511. FATIGUE AND FRACTURE. 3.0 Semester Hrs.**
Equivalent with MTGN545,
(I) Basic fracture mechanics as applied to engineering materials, S-N curves, the Goodman diagram, stress concentrations, residual stress effects, effect of material properties on mechanisms of crack propagation. Prerequisite: none. 3 hours lecture; 3 semester hours. Fall semesters, odd numbered years.

**MEGN512. ADVANCED ENGINEERING VIBRATION. 3.0 Semester Hrs.**
Vibration theory as applied to single- and multi-degree-of freedom systems. Free and forced vibrations to different types of loading-harmonic, impulse, periodic and general. Natural frequencies. Role of Damping. Importance of resonance. Modal superposition method. Prerequisite: MEGN315, 3 hours lecture; 3 semester hours.

**MEGN513. KINETIC PHENOMENA IN MATERIALS. 3.0 Semester Hrs.**
Equivalent with MLGN511,
(I) Linear irreversible thermodynamics, dorce-flux couplings, diffusion, crystalline materials, amorphous materials, defect kinetics in crystalline materials, interface kinetics, morphological evolution of interfaces, nucleation theory, crystal growth, coarsening phenomena and grain growth, solidification, spinodal decomposition. Prerequisites: MATH225: Differential equations (or equivalent), MLGN504/MTGN555/CBEN509: Thermodynamics (or its equivalent).

**MEGN514. CONTINUUM MECHANICS. 3.0 Semester Hrs.**
(I) This is a graduate course covering fundamentals of continuum mechanics and constitutive modeling. The goal of the course is to provide graduate students interested in fluid and solid mechanics with the foundation necessary to review and write papers in the field. Students will also gain experience interpreting, formulating, deriving, and implementing three-dimensional constitutive laws. The course explores six subjects: 1. Mathematical Preliminaries of Continuum Mechanics (Vectors, Tensors, Indicial Notation, Tensor Properties and Operations, Coordinate Transformations) 2. Stress (Traction, Invariants, Principal Values) 3. Motion and Deformation (Deformation Rates, Geometric Measures, Strain Tensors, Linearized Displacement Gradients) 4. Balance Laws (Conservation of Mass, Momentum, Energy) 5. Ideal Constitutive Relations (Frictionless & Linearly Viscous Fluids, Elasticity) 6. Constitutive Modeling (Formulation, Derivation, Implementation, Programming). 3 hours lecture, 3 semester hours.

**MEGN515. COMPUTATIONAL MECHANICS. 3.0 Semester Hrs.**
(I) A graduate course in computational mechanics with an emphasis on a studying the major numerical techniques used to solve problems that arise in mechanics and some related topical areas. Variational methods are applied throughout as a general approach in the development of many of these computational techniques. A wide range of problems are addressed in one- and two- dimensions which include linear and nonlinear elastic and elastoplastic steady state mechanics problems. Computational algorithms for time dependent problems such as transient dynamics and viscoplasticity are also addressed. In the latter part of the course an introduction to computational methods employing boundary integral equations, and particle methods for solving the mechanical behavior of multi-body systems are also given. Note all the software used in this course is written in MATLAB which has become a widely acceptable engineering programming tool. 3 lecture hours, 3 semester hours. Prerequisite: MEGN502.

**MEGN517. INELASTIC CONSTITUTIVE RELATIONS. 3.0 Semester Hrs.**
(II) This is a graduate course on inelastic constitutive relations of solid materials. The goal of the course is to provide students working in solid mechanics and metallurgy with a foundation in theory and models of inelastic material behaviors. The behaviors we cover include plasticity, thermoelasticity, nonlinear elasticity, and phase transformations. We dive in at several length scales - crystal mechanics and phenomenological thermodynamic internal variable theory. We also discuss ties between models and state of the art experimental mechanics, including in-situ diffraction. We will cover both theory and numerical implementation strategies for the topics. Thus, students will gain experience interpreting, formulating, deriving, and implementing three-dimensional constitutive laws and crystal mechanics models. We will introduce many topics rather than focusing on a few such that students have a foot-in to dive deeper on their own, as they will do in the project. Prerequisites: MEGN514. 3 hours lecture, 3 semester hours.

**MEGN520. BOUNDARY ELEMENT METHODS. 3.0 Semester Hrs.**
(II) Development of the fundamental theory of the boundary element method with applications in elasticity, heat transfer, diffusion, and wave propagation. Derivation of indirect and direct boundary integral equations. Introduction to other Green?s function based methods of analysis. Computational experiments in primarily two dimensions. Prerequisite: MEGN502. 3 hours lecture; 3 semester hours Spring Semester, odd numbered years.

**MEGN521. INTRODUCTION TO DISCRETE ELEMENT METHODS (DEMS). 3.0 Semester Hrs.**
(I) Review of particle/rigid body dynamics, numerical DEM solution of equations of motion for a system of particles/rigid bodies, linear and nonlinear contact and impact laws dynamics, applications of DEM in mechanical engineering, materials processing and geo-mechanics. Prerequisites: CEEN311, MEGN315 and some scientific programming experience in C/C++ or Fortran. 3 hours lecture; 3 semester hours Spring semester of even numbered years.

**MEGN531. PROSTHETIC AND IMPLANT ENGINEERING. 3.0 Semester Hrs.**
Prosthetics and implants for the musculoskeletal and other systems of the human body are becoming increasingly sophisticated. From simple joint replacements to myoelectric limb replacements and functional electrical stimulation, the engineering opportunities continue to expand. This course builds on musculoskeletal biomechanics and other BELS courses to provide engineering students with an introduction to prosthetics and implants for the musculoskeletal system. At the end of the semester, students should have a working knowledge of the challenges and special considerations necessary to apply engineering principles to augmentation or replacement in the musculoskeletal system. Prerequisite: MEGN430.

**MEGN532. EXPERIMENTAL METHODS IN BIOMECHANICS. 3.0 Semester Hrs.**
(I) Introduction to experimental methods in biomechanical research. Topics include experimental design, hypothesis testing, motion capture, kinematic models, ground reaction force data collection, electromyography, inverse dynamics calculations, and applications. Strong emphasis on hands-on data collection and technical presentation of results. The course will culminate in individual projects combining multiple experimental measurement techniques. Prerequisite: Graduate Student Standing. 3 hours lecture; 3.0 semester hours.

**MEGN535. MODELING AND SIMULATION OF HUMAN MOVEMENT. 3.0 Semester Hrs.**
Introduction to modeling and simulation in biomechanics. The course includes a synthesis of musculoskeletal properties, interactions with the environment, and computational optimization to construct detailed computer models and simulations of human movement. Prerequisite: MEGN315 and MEGN330.

**MEGN536. COMPUTATIONAL BIOMECHANICS. 3.0 Semester Hrs.**
Computational Biomechanics provides an introduction to the application of computer simulation to solve fundamental problems in biomechanics and bioengineering. Musculoskeletal biomechanics, joint kinematics, medical image reconstruction, hard and soft tissue modeling, and medical device design are considered in the context of a semester-long project to develop and evaluate an artificial knee implant. Leading commercial software tools are introduced with hands-on exercises. An emphasis is placed on understanding the limitations of the computer model as a predictive tool and the need for rigorous verification and validation of all modeling tasks. Clinical application of biomechanical modeling tools is highlighted and impact on patient quality of life is discussed. Prerequisite: MEGN330, MEGN324.

**MEGN537. PROBABILISTIC BIOMECHANICS. 3.0 Semester Hrs.**
The course introduces the application of probabilistic analysis methods in biomechanical systems. All real engineering systems, and especially human systems, contain inherent uncertainty due to normal variations in dimensional parameters, material properties, motion profiles, and loading conditions. The purpose of this course is to examine methods for including these sources of variation in biomechanical computations. Concepts of basic probability will be reviewed and applied in the context of engineering reliability analysis. Probabilistic analysis methods will be introduced and examples specifically pertaining to musculoskeletal biomechanics will be studied. Prerequisite: MEGN436 or MEGN536.

**MEGN540. MECHATRONICS. 3.0 Semester Hrs.**
(II) A course focusing on implementation aspects of mechatronic and control systems. Significant lab component involving embedded C programming on a mechatronics teaching platform, called a "haptic paddle", a single degree-of-freedom force-feedback joystick. Prerequisite: Graduate standing. 3 hours lecture; 3 semester hours.

**MEGN544. ROBOT MECHANICS: KINEMATICS, DYNAMICS, AND CONTROL. 3.0 Semester Hrs.**
(I) Mathematical representation of robot structures. Mechanical analysis including kinematics, dynamics, and design of robot manipulators. Representations for trajectories and path planning for robots. Fundamentals of robot control including, linear, nonlinear and force control methods. Introduction to off-line programming techniques and simulation. Prerequisite: EENG307 and MEGN441. 3 hours lecture; 3 semester hours.

**MEGN545. ADVANCED ROBOT CONTROL. 3.0 Semester Hrs.**
The focus is on mobile robotic vehicles. Topics covered are: navigation, mining applications, sensors, including vision, problems of sensing variations in rock properties, problems of representing human knowledge in control systems, machine condition diagnostics, kinematics, and path planning real time obstacle avoidance. Prerequisite: EENG307.

**MEGN551. ADVANCED FLUID MECHANICS. 3.0 Semester Hrs.**
(I) This first year graduate course covers the fundamentals of incompressible fluid mechanics with a focus on differential analysis and building a strong foundation in the prerequisite concepts required for subsequent study of computational fluid dynamics and turbulence. The course is roughly divided into four parts covering (i) the governing equations of fluid mechanics, (ii) Stokes flows and ideal-fluid flows, (iii) boundary layer flows, and (iv) hydrodynamic stability and transition to turbulence. Prerequisites: MEGN351. 3 hours lecture; 3 semester hours.

**MEGN552. VISCOUS FLOW AND BOUNDARY LAYERS. 3.0 Semester Hrs.**
(I) This course establishes the theoretical underpinnings of fluid mechanics, including fluid kinematics, stress-strain relationships, and derivation of the fluid-mechanical conservation equations. These include the mass-continuity and Navier-Stokes equations as well as the multi-component energy and species-conservation equations. Fluid-mechanical boundary-layer theory is developed and applied to situations arising in chemically reacting flow applications including combustion, chemical processing, and thin-film materials processing. Prerequisite: MEGN451, or CBEN430. 3 hours lecture; 3 semester hours.

**MEGN553. INTRODUCTION TO COMPUTATIONAL TECHNIQUES FOR FLUID DYNAMICS AND TRANSPORT PHENOMENA. 3.0 Semester Hrs.**
(II) Introduction to Computational Fluid Dynamics (CFD) for graduate students with no prior knowledge of this topic. Basic techniques for the numerical analysis of fluid flows. Acquisition of hands-on experience in the development of numerical algorithms and codes for the numerical modeling and simulation of flows and transport phenomena of practical and fundamental interest. Capabilities and limitations of CFD. Prerequisite: MEGN451. 3 hours lecture; 3 semester hours.

**MEGN560. DESIGN AND SIMULATION OF THERMAL SYSTEMS. 3.0 Semester Hrs.**
In this course the principles of design, modeling, analysis, and optimization of processes, devices, and systems are introduced and applied to conventional and advanced energy conversion systems. It is intended to integrate conservation principles of thermodynamics (MEGN361) with the mechanism relations of fluid mechanics (MEGN351) and heat transfer (MEGN471). The course begins with general system design approaches and requirements and proceeds with mathematical modeling, simulation, analysis, and optimization methods. The design and simulation of energy systems is inherently computational and involves modeling of thermal equipment, system simulation using performance characteristics, thermodynamic properties, mechanistic relations, and optimization (typically with economic-based objective functions). Fundamental principles for steady-state and dynamic modeling are covered. Methods for system simulation which involves predicting performance with a given design (fixed geometry) are studied. Analysis methods that include Pinch Technology, Exergy Analysis, and Thermo-economics are examined and are considered complementary to achieving optimal designs. Optimization encompasses objective function formulation, systems analytical methods, and programming techniques. System optimization of the design and operating parameters of a configuration using various objective functions are explored through case studies and problem sets. Economics and optimization for analyses and design of advanced energy systems, such as Rankine and Brayton cycle power plants, combined heat and power, refrigeration and geothermal systems, fuel cells, turbomachinery, and heat transfer equipment are a focus. 3 lecture hours; 3 credit hours.

**MEGN561. ADVANCED ENGINEERING THERMODYNAMICS. 3.0 Semester Hrs.**
(I) First year graduate course in engineering thermodynamics that emphasizes a greater depth of study of undergraduate subject matter and an advancement to more complex analyses and topics. The course begins with fundamental concepts, 1st and 2nd Law analyses of processes, devices, and systems and advances to equations of state, property relations, ideal and non-ideal gas mixtures, chemically reacting systems, and phase equilibrium. Historical and modern contexts on the development and advancements of thermodynamic concepts are given. Fundamental concepts are explored through the analysis of advanced thermodynamic phenomena and use of computational tools to solve more realistic problems. Prerequisites: MEGN351, MEGN361, and MEGN471. 3 hours lecture; 3 semester hours.

**MEGN566. COMBUSTION. 3.0 Semester Hrs.**
(I) An introduction to combustion. Course subjects include: the development of the Chapman-Jouget solutions for deflagration and detonation, a brief review of the fundamentals of kinetics and thermochemistry, development of solutions for diffusion flames and premixed flames, discussion of flame structure, pollutant formation, and combustion in practical systems. Prerequisite: MEGN451 or CBEN430. 3 hours lecture; 3 semester hours.

**MEGN567. PRINCIPLES OF BUILDING SCIENCE. 3.0 Semester Hrs.**
(I) First or second year graduate course that covers the fundamentals of building energy systems, moist air processes, heating, ventilation, and air conditioning (HVAC) systems and the use of numerical models for heat and mass transfer to analyze advanced building technologies such as phase change materials, green roofs or cross laminated timber. Prerequisites: MEGN351, MEGN361, MEGN471. 3 hours lecture; 3 semester hours.

**MEGN569. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.**
Equivalent with CBEN569,CHEN569,MLGN569,MTGN569,
(I) Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical-thermodynamics and materials- science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. 3 credit hours.

**MEGN570. ELECTROCHEMICAL SYSTEMS ENGINEERING. 3.0 Semester Hrs.**
(I) In this course, students will gain fundamental, quantitative insight into the operation of electrochemical devices for engineering analysis across a range of length scales and applications. The course will use the development of numerical models as a lens through which to view electrochemical devices. However, the course will also deal extensively with "real world" systems and issues, including experimental characterization, system optimization and design, and the cyclical interplay between models and physical systems. The course begins by establishing the equations that govern device performance at the most fundamental level, describing chemical and electrochemical reactions, heat transfer, transport of charged and neutral species, and material properties in operating devices. Subsequently, these equations will be used to discuss and analyze engineering issues facing three basic types of electrochemical devices: fuel cells, batteries, and sensors. At each juncture will evaluate our equations to determine when simpler models may be more suitable. Throughout the semester, concepts will be applied in homework assignments, including an over-arching, semester-long project to build detailed numerical models for an application of each student's choosing. 3 hours lecture; 3 semester hours.

**MEGN571. ADVANCED HEAT TRANSFER. 3.0 Semester Hrs.**
An advanced course in heat transfer that supplements topics covered in MEGN471. Derivation and solution of governing heat transfer equations from conservation laws. Development of analytical and numerical models for conduction, convection, and radiation heat transfer, including transient, multidimensional, and multimode problems. Introduction to turbulence, boiling and condensation, and radiative transfer in participating media. Prerequisite: MEGN471.

**MEGN583. ADDITIVE MANUFACTURING. 3.0 Semester Hrs.**
(II) Additive Manufacturing (AM), also known as 3D Printing in the popular press, is an emerging manufacturing technology that will see widespread adoption across a wide range of industries during your career. Subtractive Manufacturing (SM) technologies (CNCs, drill presses, lathes, etc.) have been an industry mainstay for over 100 years. The transition from SM to AM technologies, the blending of SM and AM technologies, and other developments in the manufacturing world has direct impact on how we design and manufacture products. This course will prepare students for the new design and manufacturing environment that AM is unlocking. The graduate section of this course differs from the undergraduate section in that graduate students perform AM-related research. While students complete quizzes and homework, they do not take a midterm or final exam. Prerequisites: MEGN200 and MEGN201 or equivalent project classes. 3 hours lecture; 3 semester hours.

**MEGN584. MODELING MATERIALS PROCESSING. 3.0 Semester Hrs.**
This course aims to enable students to examine a given materials processing operation or manufacturing problem, identify the important phenomena, develop simple quantitative models of those phenomena, and apply them to obtain reasonable solutions to practical design issues and problems. Phenomena involving fluid flow, heat transfer, solidification, diffusion, and thermal-mechanical behavior are related to terms in governing equations based on heat, mass, and momentum balances. These equations are simplified by formal estimation and scaling to create mechanistic process models, often selected from classic analytical solutions. Example applications to manufacturing processes for metals and polymers include controlled cooling, extrusion, casting, and welding. Prerequisite: Undergraduate degree in Mechanical Engineering or equivalent (that includes relevant courses of calculus, differential equations, materials and/or manufacturing, heat transer, fluid mechanics, and solid mechanics) or instructor consent.

**MEGN585. NETWORK MODELS. 3.0 Semester Hrs.**
(I) We examine network flow models that arise in manufacturing, energy, mining, transportation and logistics: minimum cost flow models in transportation, shortest path problems in assigning inspection effort on a manufacturing line, and maximum flow models to allocate machine-hours to jobs. We also discuss an algorithm or two applicable to each problem class. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. Offered every other year. 3 hours lecture; 3 semester hours.

**MEGN586. LINEAR OPTIMIZATION. 3.0 Semester Hrs.**
(I) We address the formulation of linear programming models, linear programs in two dimensions, standard form, the Simplex method, duality theory, complementary slackness conditions, sensitivity analysis, and multi-objective programming. Applications of linear programming models include, but are not limited to, the areas of manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. Offered every other year. 3 hours lecture; 3 semester hours.

**MEGN587. NONLINEAR OPTIMIZATION. 3.0 Semester Hrs.**
Equivalent with MEGN487,
(II) We address both unconstrained and constrained nonlinear model formulation and corresponding algorithms (e.g., Gradient Search and Newton's Method, and Lagrange Multiplier Methods and Reduced Gradient Algorithms, respectively). Applications of state-of-the-art hardware and software will emphasize solving real-world engineering problems in areas such as manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with an algorithm such as MINOS) these optimization problems is introduced. Prerequisite: MATH111. 3 hours lecture; 3 semester hours.

**MEGN588. INTEGER OPTIMIZATION. 3.0 Semester Hrs.**
Equivalent with MEGN488,
(I) We address the formulation of integer programming models, the brand-and-bound algorithm, total unimodularity and the ease with which these models are solved, and then suggest methods to increase tractability, including cuts, strong formulations, and decomposition techniques, e.g., Lagrangian relaxation, Benders decomposition. Applications include manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. Prerequisite: none. 3 hours lecture; 3 semester hours. Years to be Offered: Every Other Year.

**MEGN592. RISK AND RELIABILITY ENGINEERING ANALYSIS AND DESIGN. 3.0 Semester Hrs.**
(I) The importance of understanding, assessing, communicating, and making decisions based in part upon risk, reliability, robustness, and uncertainty is rapidly increasing in a variety of industries (e.g.: petroleum, electric power production, etc.) and has been a focus of some industries for many decades (e.g.: nuclear power, aerospace, automotive, etc). This graduate class will provide the student with a technical understanding of and ability to use common risk assessment tools such as Reliability Block Diagrams (RBD), Failure Modes and Effects Analysis (FMEA), and Probabilistic Risk Assessment (PRA); and new tools being developed in universities including Function Failure Design Methods (FFDM), Function Failure Identification and Propagation (FFIP), and Uncoupled Failure Flow State Reasoning (UFFSR) among others. Students will also be provided with a high-level overview of what risk really means and how to contextualize risk information. Methods of communicating and making decisions based in part upon risk information will be discussed. 3 hours lecture, 3 semester hours.

**MEGN597. CASE STUDY - MATERIALS SCIENCE. 0.5-6 Semester Hr.**
Individual research or special problem projects supervised by a faculty member.

**MEGN598. SPECIAL TOPICS IN MECHANICAL ENGINEERING. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**MEGN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**MEGN671. RADIATION HEAT TRANSFER. 3.0 Semester Hrs.**
Accurate radiative transfer models are essential in many fields, including: combustion, propulsion, astronomy, solar technology, and climate science, to name only a few. The complex nature of radiative transfer can be intimidating, and calculations can be computationally expensive. In the first half of this course, we will study the role of material and surface properties on radiative transfer and develop and solve models for radiation exchange between surfaces (applicable to solar technology and high temperature systems). In the second half of the course, we will tackle radiation propagation through absorbing, scattering, and emitting media (gases, aerosols, semitransparent materials). We will model these systems using the Radiative Transfer Equation (RTE) and explore a few approaches to solving the RTE for select environments. Prerequisite: MEGN471.

**MEGN686. ADVANCED LINEAR OPTIMIZATION. 3.0 Semester Hrs.**
(II) As an advanced course in optimization, we expand upon topics in linear programming: advanced formulation, the dual simplex method, the interior point method, algorithmic tuning for linear programs (including numerical stability considerations), column generation, and Dantzig-Wolfe decomposition. Time permitting, dynamic programming is introduced. Applications of state-of-the-art hardware and software emphasize solving real-world problems in areas such as manufacturing, mining, energy, transportation and logistics, and the military. Computers are used for model formulation and solution. Offered every other year. Prerequisite: MEGN586. 3 hours lecture; 3 semester hours.

**MEGN688. ADVANCED INTEGER OPTIMIZATION. 3.0 Semester Hrs.**
(II) As an advanced course in optimization, we expand upon topics in integer programming: advanced formulation, strong integer programming formulations (e.g., symmetry elimination, variable elimination, persistence), in-depth mixed integer programming cuts, rounding heuristics, constraint programming, and decompositions. Applications of state-of-the-art hardware and software emphasize solving real-world problems in areas such as manufacturing, mining, energy, transportation and logistics, and the military. Computers are used for model formulation and solution. Prerequisite: MEGN588. 3 hours lecture; 3 semester hours. Years to be Offered: Every Other Year.

**MEGN698. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**MEGN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**MEGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

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**DTCN501. INTRODUCTION TO DATA CENTER ENGINEERING. 3.0 Semester Hrs.**
(I, II) This unique course will develop students' foundational knowledge in critical disciplines related to large-scale data center infrastructure design and performance. The course is intended for students with a B.S. in engineering, computer science, or applied and engineering physics who are interested in careers and/or opportunities in data center engineering and management. The course will incorporate real data center examples for introducing analysis of data center design and computing hardware and network requirements; engineering principles for data center power system design, distribution, and control; heat transfer systems for computer system thermal management and building HVAC; and large-scale data file organization, information system architecture, and network and software security. The course will conclude with lectures and an assignment related to sustainability and robustness for data center engineering and design. 3 hours lecture; 3 semester hours.

**DTCN502. DATA CENTER INFRASTRUCTURE MANAGEMENT. 3.0 Semester Hrs.**
(I, II) This course conveys the basic principles for operating, managing, and optimizing the hardware and software necessary for a large, modern data center. Students will learn how data center components are integrated and managed through software for various applications and in general for security, efficiency, adaptability, robustness, and sustainability. It is intended for graduate students with backgrounds in engineering or computer science. The students will become familiar with best practices in the industry and will demonstrate their knowledge by developing a operations management plan for a specific data center application. 3 hours lecture; 3 semester hours.

**DTCN503. DATA CENTER ENGINEERING GRADUATE SEMINAR. 1.0 Semester Hr.**
(I, II) The Data Center Engineering Seminar will provide students a broad knowledge of current industry and research developments in analysis, design, and operations of Data Center Engineering through once a week discussions and/or seminars from invited guest speakers presenting topics related to data center design, operations, and economics. Students will prepare several short reports on industry developments and/or academic research related to presentations and will deliver a technical presentation and lead a subsequent discussion on an approved topic relevant for the industry. Corequisite: DTCN501. 1 hour seminar; 1 semester hour.

**DTCN591. DATA CENTER ENGINEERING DESIGN AND ANALYSIS. 2.0 Semester Hrs.**
(I, II) In this graduate-level course, students will participate in a directed team-based project learning through planning, designing, and analyzing a large, modern data center for an industry- or government-relevant application. The course will build on content learned in pre-requisite courses on an Introduction to Data Center Engineering and on Data Center Infrastructure Management. Students will collaborate in multi-disciplinary teams to develop and present the design and analysis of a large, modern data center design for an industry or government application. 2 hours seminar; 2 semester hours.

**FEGN525. ADVANCED FEA THEORY & PRACTICE. 3.0 Semester Hrs.**
This course examines the theory and practice of finite element analysis. Direct methods of deriving the FEA governing equations are addressed as well as more advanced techniques based on virtual work and variational methods. Common 1D, 2D, and 3D element formulations are derived, and key limitations examined. Matlab is used extensively to build intuition for FEA solution methods and students will create their own 2D FEA code by the end of the course. The commercial FEA software Abaqus is introduced with hands-on examples and Matlab solutions are compared to Abaqus for model validation.

**FEGN526. STATIC AND DYNAMIC APPLICATIONS IN FEA. 3.0 Semester Hrs.**
This course emphasizes proficiency with commercial FEA software for solution of practical static, quasistatic, and dynamic structural problems. Common 1D, 2D, and 3D elements are examined in the context of linear solution techniques. Students will explore efficient methods for model construction and solution with commercial tools (the Abaqus FEA software). Emphasis will also be placed on verification, validation, and reporting standards for effective application of FEA software tools. Online course. Prerequisite: FEGN525.

**FEGN527. NONLINEAR APPLICATIONS IN FEA. 3.0 Semester Hrs.**
This course explores common nonlinearities frequently encountered in structural applications of FEA. Students will gain proficiency in modeling geometric nonlinearity (large strains), boundary nonlinearity due to contact, and material nonlinearity (creep, rate dependence, plasticity, temperature effects, residual stress). The commercial FEA software Abaqus is used for hands-on experience. Online course. Prerequisite: FEGN526.

**FEGN528. FEA FOR ADVANCED DESIGN APPLICATIONS. 3.0 Semester Hrs.**
In this course students will learn the automation tools and methods necessary for effective application of FEA on advanced design problems. Strategies for parametric analysis, performance optimization, and consideration of statistical uncertainty will be examined using Python scripting and commercial automation software. Online course. Prerequisite: FEGN526.

## Professor and Department Head

John Berger

## George R. Brown Distinguished Professor

Robert J. Kee

## Professors

Cristian V. Ciobanu

Gregory S. Jackson

Alexandra Newman

Brian G. Thomas

## Associate Professor

Steven DeCaluwe

Garritt Tucker

Mohsen Asle Zaeem

Joel M. Bach

Gregory Bogin

Robert Braun

Mark Deinert

Leslie Lamberson

Anthony J. Petrella

Jason Porter, Assistant Department head for Graduate Studies

Anne Silverman

Aaron Stebner

Neal Sullivan

Ruichong "Ray" Zhang

Xiaoli Zhang

## Assistant Professor

Owen Hildreth

Andrew Osborne

Andrew Petruska

Paulo Tabares-Velasco

Nils Tilton

## Teaching Professors

Jennifer Blacklock

Kristine Csavina, Assistant Department Head for Undergraduate Studies

Ventzi Karaivanov

## Teaching Associate Professors

Oyvind Nilsen

Derrick Rodriguez

## Teaching Assistant Professors

Jeffrey Ackerman

Kelly Rickey

Greg VanderBeek

Jeffrey Wheeler

James Wong

## Emeriti Professor

Robert King

Michael B. McGrath

Graham Mustoe

Terry E. Parker

## Emerita Professor

Joan P. Gosink

## Emeriti Associate Professor

Dave Munoz

Graham G.W. Mustoe

John P.H. Steele

## Research Professor

George Gilmer

## Research Associate Professors

Angel Abbud-Madrid

Sandrine Ricote

Huayang Zhu

## Research Assistant Professors

Aminahmed Behnam

Christopher B. Dreyer

Branden Kappes

Canan Karakaya

Amy Schweikert

## Affiliate Professor of Mechanical Engineering

Michael Mooney

## Post-Doctoral Fellow

Gupta Ankit

Rajesh Jah

Yasuhito Suzuki

## Professor of Practice

Craig Brice

George Sowers

# Metallurgical and Materials Engineering

## Degrees Offered

- Master of Engineering (Metallurgical and Materials Engineering)
- Master of Science (Metallurgical and Materials Engineering)
- Doctor of Philosophy (Metallurgical and Materials Engineering)

## Program Description

The program of study for the Master or Doctor of Philosophy degrees in Metallurgical and Materials Engineering is selected by the student in consultation with her or his advisor, and with the approval of the Thesis Committee. The program can be tailored within the framework of the regulations of the Graduate School to match the student's interests while maintaining the main theme of materials engineering and processing. There are three areas of specialization within the Department:

- Physical and Mechanical Metallurgy;
- Physicochemical Processing of Materials; and,
- Ceramic Engineering.

The Department is home to six research centers:

- Advanced Coatings and Surface Engineering Laboratory (ACSEL);
- Advanced Steel Processing and Products Research Center (ASPPRC);
- Center for Advanced Non Ferrous Structural Alloys (CANFSA)
- Center for Welding Joining, and Coatings Research (CWJCR);
- Colorado Center for Advanced Ceramics (CCAC); and,
- Kroll Institute for Extractive Metallurgy (KIEM).

The Nuclear Science and Engineering Center (NuSEC) also operates closely with the Department.

A Graduate Certificate is offered by each Department Center – the requirements for the Graduate Certificate are:

1. Be admitted to MME Graduate Certificate Program upon the recommendation of the MME Department.
2. Complete a total of 12 hours of course credits of which only 3 credit hours can be at the 400 level.

The specific courses to be taken are determined by the Graduate Advisor in the Department Center selected by the candidate. A cumulative grade point average of B or better must be maintained while completing these requirements.

## Degree Program Requirements

The program requirements for the three graduate degrees offered by the Department are listed below:

## Master of Engineering Degree

Requirements: A **minimum total of 30.0 credit hours** consisting of:

| Coursework | Credits |
|---|---|
| Approved Coursework* | 18.0 - 26.0 |
| MTGN501 - MME GRADUATE SEMINAR** | 1.0 |
| MTGN700 - GRADUATE RESEARCH CREDIT: MASTER OF ENGINEERING or DESIGNATED DESIGN COURSE*** | 3.0 - 5.0 |

* 18 of the 26 credit hours must be taken from the Metallurgy or Materials Science courses. All other course credits can be taken in any department.

** Students are expected to enroll in this seminar every semester, but a maximum of 1 credit hour may apply toward the degree.

*** 3.0 - 5.0 credits, to include MTGN700, or from Designated Design courses below.

**Designated Design courses include:**

| | | |
|---|---|---|
| MTGN414 | ADVANCED PROCESSING AND SINTERING OF CERAMICS | 3.0 |
| MTGN445 | MECHANICAL PROPERTIES OF MATERIALS | 3.0 |
| MTGN450 | STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS | 3.0 |
| MTGN461 | TRANSPORT PHENOMENA AND REACTOR DESIGN FOR METALLURGICAL AND MATERIALS ENGINEERS | 3.0 |
| MTGN464 | FORGING AND FORMING | 2.0 |
| MTGN466 | MATERIALS DESIGN: SYNTHESIS, CHARACTERIZATION AND SELECTION | 3.0 |
| MTGN475 | METALLURGY OF WELDING | 2.0 |
| MTGN549 | CURRENT DEVELOPMENTS IN FERROUS ALLOYS | 3.0 |
| MTGN564 | ADVANCED FORGING AND FORMING | 3.0 |
| MTGN560 | ANALYSIS OF METALLURGICAL FAILURES | 3.0 |

Alternative courses can be substituted with approval from the advisor and department head

**Restrictions:**

1. Only three (3) credit hours of independent coursework, e.g. MTGN599, may be applied toward the degree.
2. A maximum of nine (9) credit hours of approved 400-level coursework may be applied toward the degree.
3. Courses taken to remove deficiencies may not be applied toward the degree.

The Master of Engineering Degree can also be obtained as part of the combined undergraduate/graduate degree program.

## Master of Science Degree

Requirements: A **minimum total of 30.0 credit hours** consisting of:

| Coursework | Credits |
|---|---|
| Approved Coursework* | 18.0 - 23.0 |

| | |
|---|---|
| MTGN501 - MME GRADUATE SEMINAR** | 1.0 |
| MTGN707 - GRADUATE THESIS / DISSERTATION RESEARCH CREDIT*** | 6.0 - 11.0 |

* Minimum of 18 credit hours of approved coursework is required. 12 credit hours must be taken from the Metallurgy or Materials Science courses. All other course credits can be taken in any department.

** Students are expected to enroll in this seminar every semester, but a maximum of 1 credit hour may apply toward the degree.

*** 6.0 to 11.0 research credit hours, to include MTGN707.

**Restrictions:**

1. Only three (3) credit hours of independent coursework, e.g. MTGN599, may be applied toward the degree.
2. A maximum of nine (9) credit hours of approved 400-level coursework may be applied toward the degree.
3. Courses taken to remove deficiencies may not be applied toward the degree.

**Additional Degree Requirements:**

1. Approval of all courses by the Thesis Committee and the Department Head. (Thesis Committee: consisting of 3 or more members, including the advisor and at least 1 additional member from the Metallurgical and Materials Engineering Department.)
2. Submittal and successful oral defense of a thesis before a Thesis Committee. The thesis must present the results of original scientific research or development.

The Master of Science Degree can also be obtained as part of the combined undergraduate/graduate degree program.

## Doctor of Philosophy Degree

Requirements: A **minimum total of 72.0 credit hours** consisting of:

| Coursework | Credits |
|---|---|
| Approved Coursework* | 36.0 - 48.0 |
| MTGN501 - MME GRADUATE SEMINAR** | 1.0 |
| MTGN707 - GRADUATE THESIS / DISSERTATION RESEARCH CREDIT*** | 24.0 - 36.0 |

* A minimum of 36.0 credit hours of approved coursework, 24 of which must be in MTGN or MLGN. Credit hours previously earned for a Master's degree may be applied, subject to approval, toward the Doctoral degree provided that the Master's degree was in Metallurgical and Materials Engineering or a similar field. At least 21.0 credit hours of approved course work must be taken at the Colorado School of Mines.
All courses and any applicable Master's degree credit-hours must be approved by the Thesis Committee and the Department Head (Thesis Committee consisting of: 4 or more members, including the advisor, at least 2 additional members from the Metallurgical and Materials Engineering Department, and at least 1 member from outside the Department.)

** Students are expected to enroll in this seminar every semester, but a maximum of 1 credit hour may apply toward the degree.

*** A minimum of 24.0 research credit hours, to include MTGN707.

**Restrictions:**

1. Only six (6) credit hours of independent coursework, e.g. MTGN599, may be applied toward the degree.
2. A maximum of nine (9) credit hours of approved 400-level coursework may be applied toward the degree.
3. Courses taken to remove deficiencies may not be applied toward the degree.

**Additional Degree Requirements:**

1. Presentation of a Proposal on the Thesis-Research Project to the Thesis Committee.
2. A passing grade on the written and oral Qualifying-Process (Q.P.) Examinations.
3. Presentation of a Progress Report on their Research Project to the Thesis Committee is strongly recommended; this presentation is usually 6 months after successfully completing the Q.P. Examinations and no fewer than 6 weeks before the Defense of Thesis.
4. Submittal and successful oral defense of a thesis before the Thesis Committee. The thesis must present the results of original scientific research or development.

## Prerequisites

The entering graduate student in the Department of Metallurgical and Materials Engineering must have completed an undergraduate program equivalent to that required for the BS degree in: Metallurgical and Materials Engineering, Materials Science or a related field. This undergraduate program should have included a background in science fundamentals and engineering principles. A student, who possesses this background but has not taken specific undergraduate courses in Metallurgical and Materials Engineering, will be allowed to rectify these course deficiencies at the beginning of their program of study.

## Mines' Combined Undergraduate / Graduate Degree Program for Non-Thesis MS

Students with continuous registration at Mines from the undergraduate to the graduate degree may fulfill part of the degree requirements by double counting six credit hours, which were also used in fulfilling the requirements of their undergraduate degree at Mines. These courses must have been passed with a “B” or better and meet all other University and Department requirements for graduate credit, but their grades are not included in calculating the graduate GPA.

# Fields of Research

## Ceramic Research

- Ceramic processing
- Ceramic-metal composites
- Functional materials
- Ion implantation
- Modeling of ceramic processing
- Solid oxide fuel cell materials and membranes
- Transparent conducting oxides

## Coatings Research

- Chemical vapor deposition
- Coating materials, films and applications
- Epitaxial growth
- Interfacial science
- Physical vapor deposition
- Surface mechanics
- Surface physics
- Tribology of thin films and coatings

## Extractive and Mineral Processing Research

- Chemical and physical processing of materials
- Electrometallurgy
- Hydrometallurgy
- Mineral processing
- Pyrometallurgy
- Recycling and recovery of materials
- Thermal plasma processing

## Nonferrous Research

- Aluminum alloys
- High entropy alloys
- Magnesium alloys
- Nonferrous structural alloys
- Shape memory alloys
- Superalloys
- Titanium alloys

## Polymers and Biomaterials Research

- Advanced polymer membranes and thin films
- Biopolymers
- Bio-mimetic and bio-inspired materials engineering
- Calcium phosphate-based ceramics
- Drug delivery
- Failure of medical devices
- Interfaces between materials and tissue
- Living/controlled polymerization
- Organic-inorganic hybrid materials
- Porous structured materials
- Self- and directed-assembly
- Structural medical alloys
- Tissue as a composite material

## Steel Research

- Advanced high strength steels
- Advanced steel coatings
- Carburized steels
- Deformation behavior of steels
- Fatigue behavior of steels
- Microalloyed steels
- Nickel-based steels
- Quench and partitioned steels
- Plate steels
- Sheet steels

## Welding and Joining Research

- Brazing of ultra wide gaps
- Explosive processing of materials
- Laser welding and processing
- Levitation for kinetics and surface tension evaluation
- Materials joining processes
- Pyrochemical kinetics studies using levitation
- Underwater and under oil welding
- Welding and joining science
- Welding rod development
- Welding stress management
- Weld metallurgy
- Weld wire development

## Nuclear Materials Research

- Nuclear materials characterization
- Nuclear materials processing
- Nuclear materials properties

## Experimental Methods

- 3D atom probe tomography
- Atomic force microscopy
- Computer modeling and simulation
- Electron microscopy
- Mathematical modeling of material processes
- Nanoindentation
- Non-destructive evaluation
- X-ray diffraction

## Other Research Areas

- Combustion synthesis
- Corrosion science and engineering
- Failure analysis
- Mechanical metallurgy
- Phase transformation and mechanism of microstructural change
- Physical metallurgy
- Reactive metals properties
- Strengthening mechanisms
- Structure-property relationships

## Courses

**MTGN501. MME GRADUATE SEMINAR. 0.5 Semester Hrs.**

(I, II) All full-time MME graduate students must attend the Metallurgical and Materials Engineering seminar. Students must take the Graduate Seminar course every semester that they are enrolled at CSM. At the end of each semester, students are assigned either a satisfactory or unsatisfactory progress grade, based on attendance, until the final semester of the student's degree program, when a letter grade is assigned based on all prior semesters' attendance grades. As a result, while these courses are taken each year, only a maximum of 1.0 hours total of course credit is conferred. Students who have official part-time status are not required to sign up for Graduate Seminar. Attendance of other seminars outside MME can substitute for seminar attendance in MME following course instructor approval. 1 hour lecture; 0.5 hours. Repeatable up to 1 hour.

**MTGN505. CRYSTALLOGRAPHY AND DIFFRACTION. 3.0 Semester Hrs.**

(I) Introduction to point symmetry operations, crystal systems, Bravais lattices, point groups, space groups, Laue classes, stereographic projections, reciprocal lattice and Ewald sphere constructions, the new International Tables for Crystallography, and, finally, how certain properties correlate with symmetry. Subsequent to the crystallography portion, the course will move into the area of diffraction and will consider the primary diffraction techniques (x-rays, electrons and neutrons) used to determine the crystal structure of materials. Other applications of diffraction such as texture and residual stress will also be considered. Prerequisites: Graduate or Senior in good standing. 3 hours lecture, 3 semester hours.

**MTGN511. SPECIAL METALLURGICAL AND MATERIALS ENGINEERING PROBLEMS. 1-3 Semester Hr.**

(I) Independent advanced work, not leading to a thesis. This may take the form of conferences, library, and laboratory work. Selection of assignment is arranged between student and a specific Department faculty-member. Prerequisite: Selection of topic. 1 to 3 semester hours. Repeatable for credit under different titles.

**MTGN512. SPECIAL METALLURGICAL AND MATERIALS ENGINEERING PROBLEMS. 1-3 Semester Hr.**

(II) Continuation of MTGN511. Prerequisite: Selection of topic. 1 to 3 semester hours. Repeatable for credit under different titles.

**MTGN514. DEFECT CHEMISTRY AND TRANSPORT PROCESSES IN CERAMIC SYSTEMS. 3.0 Semester Hrs.**

(I) Ceramic materials science in the area of structural imperfections, their chemistry, and their relation to mass and charge transport; defects and diffusion, sintering, and grain growth with particular emphasis on the relation of fundamental transport phenomena to sintering and microstructure development and control. Prerequisites: DCGN209 or MTGN351; MTGN311. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN516. MICROSTRUCTURE OF CERAMIC SYSTEMS. 3.0 Semester Hrs.**

(II) Analysis of the chemical and physical processes controlling microstructure development in ceramic systems. Development of the glassy phase in ceramic systems and the resulting properties. Relationship of microstructure to chemical, electrical, and mechanical properties of ceramics. Application to strengthening and toughening in ceramic composite system. Prerequisite: Graduate status. 3 hours lecture; 3 semester hours. (Spring of even years only.).

**MTGN517. REFRACTORIES. 3.0 Semester Hrs.**

(I) The manufacture, testing, and use of basic, neutral, acid, and specialty refractories are presented. Special emphasis is placed on the relationship between physical properties of the various refractories and their uses in the metallurgical industry. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MTGN518. PHASE EQUILIBRIA IN CERAMIC SYSTEMS. 3.0 Semester Hrs.**

(II) Application of one to four component oxide diagrams to ceramic engineering problems. Emphasis on refractories and glasses and their interaction with metallic systems. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN523. APPLIED SURFACE AND SOLUTION CHEMISTRY. 3.0 Semester Hrs.**

(II) Solution and surface chemistry of importance in mineral and metallurgical operations. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN526. GEL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.**

An introduction to the science and technology of particulate and polymeric gels, emphasizing inorganic systems. Interparticle forces. Aggregation, network formation, percolation, and the gel transition. Gel structure, rheology, and mechanical properties. Application to solid-liquid separation operations (filtration, centrifugation, sedimentation) and to ceramics processing. Prerequisite: Graduate Status. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN527. SOLID WASTE MINIMIZATION AND RECYCLING. 3.0 Semester Hrs.**

(II) Industrial case-studies, on the application of engineering principles to minimize waste formation and to meet solid waste recycling challenges. Proven and emerging solutions to solid waste environmental problems, especially those associated with metals. Prerequisites: ESGN500 and ESGN504. 3 hours lecture; 3 semester hours.

**MTGN528. EXTRACTIVE METALLURGY OF COPPER, GOLD AND SILVER. 3.0 Semester Hrs.**

Practical applications of fundamentals of chemical-processing-of-materials to the extraction of gold, silver and copper. Topics covered include: History; Ore deposits and mineralogy; Process Selection; Hydrometallurgy and leaching; Oxidation pretreatment; Purification and recovery; Refinement; Waste treatment; and Industrial examples. Prerequisites: Graduate or Senior in good-standing. 3 hours lecture, 3 semester hours.

**MTGN529. METALLURGICAL ENVIRONMENT. 3.0 Semester Hrs.**

(I) Effluents, wastes, and their point sources associated with metallurgical processes, such as mineral concentration and values extraction? providing for an interface between metallurgical process engineering and the environmental engineering areas. Fundamentals of metallurgical unit operations and unit processes, applied to waste and effluents control, recycling, and waste disposal. Examples which incorporate engineering design and cost components are included. Prerequisites: MTGN334. 3 hours lecture; 3 semester hours.

**MTGN530. ADVANCED IRON AND STEELMAKING. 3.0 Semester Hrs.**

(I) Physicochemical principles of gas-slag-metal reactions applied to the reduction of iron ore concentrates and to the refining of liquid iron to steel. The role of these reactions in reactor design?blast furnace and direct iron smelting furnace, pneumatic steelmaking furnace, refining slags, deoxidation and degassing, ladle metallurgy, alloying, and continuous casting of steel. Prerequisite: DCGN209 or MTGN351. 3 hours lecture; 3 semester hours. (Fall of even years only.).

**MTGN531. THERMODYNAMICS OF METALLURGICAL AND MATERIALS PROCESSING. 3.0 Semester Hrs.**

(I) Application of thermodynamics to the processing of metals and materials, with emphasis on the use of thermodynamics in the development and optimization of processing systems. Focus areas will include entropy and enthalpy, reaction equilibrium, solution thermodynamics, methods for analysis and correlation of thermodynamics data, thermodynamic analysis of phase diagrams, thermodynamics of surfaces, thermodynamics of defect structures, and irreversible thermodynamics. Attention will be given to experimental methods for the measurement of thermodynamic quantities. Prerequisite: MTGN351. 3 hours lecture; 3 semester hours.

**MTGN532. PARTICULATE MATERIAL PROCESSING I - COMMINUTION AND PHYSICAL SEPARATIONS. 3.0 Semester Hrs.**

An introduction to the fundamental principles and design criteria for the selection and use of standard mineral processing unit operations in comminution and physical separation. Topics covered include: crushing (jaw, cone, gyratory), grinding (ball, pebble, rod, SAG, HPGR), screening, thickening, sedimentation, filtration and hydrocyclones. Two standard mineral processing plant-design simulation software (MinOCad and JK SimMet) are used in the course. Prerequisites: Graduate or Senior in good- standing. 3 hours lecture, 3 semester hours.

**MTGN533. PARTICULATE MATERIAL PROCESSING II - APPLIED SEPARATIONS. 3.0 Semester Hrs.**

An introduction to the fundamental principles and design criteria for the selection and use of standard mineral processing unit operations in applied separations. Topics covered include: photometric ore sorting, magnetic separation, dense media separation, gravity separation, electrostatic separation and flotation (surface chemistry, reagents selection, laboratory testing procedures, design and simulation). Two standard mineral processing plant-design simulation software (MinOCad and JK SimMet) are used in the course. Graduate or Senior in good-standing. 3 hours lecture, 3 semester hours.

**MTGN534. CASE STUDIES IN PROCESS DEVELOPMENT. 3.0 Semester Hrs.**

A study of the steps required for development of a mineral recovery process. Technical, economic, and human factors involved in bringing a process concept into commercial production. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MTGN535. PYROMETALLURGICAL PROCESSES. 3.0 Semester Hrs.**

(II) Detailed study of a selected few processes, illustrating the application of the principles of physical chemistry (both thermodynamics and kinetics) and chemical engineering (heat and mass transfer, fluid flow, plant design, fuel technology, etc.) to process development. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MTGN536. OPTIMIZATION AND CONTROL OF METALLURGICAL SYSTEMS. 3.0 Semester Hrs.**

Application of modern optimization and control theory to the analysis of specific systems in extractive metallurgy and mineral processing. Mathematical modeling, linear control analysis, dynamic response, and indirect optimum seeking techniques applied to the process analysis of grinding, screening, filtration, leaching, precipitation of metals from solution, and blast furnace reduction of metals. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MTGN537. ELECTROMETALLURGY. 3.0 Semester Hrs.**

(II) Electrochemical nature of metallurgical processes. Kinetics of electrode reactions. Electrochemical oxidation and reduction. Complex electrode reactions. Mixed potential systems. Cell design and optimization of electrometallurgical processes. Batteries and fuel cells. Some aspects of corrosion. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of even years only.).

**MTGN538. HYDROMETALLURGY. 3.0 Semester Hrs.**

(II) Kinetics of liquid-solid reactions. Theory of uniformly accessible surfaces. Hydrometallurgy of sulfide and oxides. Cementation and hydrogen reduction. Ion exchange and solvent extraction. Physicochemical phenomena at high pressures. Microbiological metallurgy. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN539. PRINCIPLES OF MATERIALS PROCESSING REACTOR DESIGN. 3.0 Semester Hrs.**

(II) Review of reactor types and idealized design equations for isothermal conditions. Residence time functions for nonreacting and reacting species and its relevance to process control. Selection of reactor type for a given application. Reversible and irreversible reactions in CSTR?s under nonisothermal conditions. Heat and mass transfer considerations and kinetics of gas-solid reactions applied to fluo-solids type reactors. Reactions in packed beds. Scale up and design of experiments. Brief introduction into drying, crystallization, and bacterial processes. Examples will be taken from current metallurgical practice. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN541. INTRODUCTORY PHYSICS OF METALS. 3.0 Semester Hrs.**

(I) Electron theory of metals. Classical and quantum-mechanical free electron theory. Electrical and thermal conductivity, thermo electric effects, theory of magnetism, specific heat, diffusion, and reaction rates. Prerequisite: MTGN445. 3 hours lecture; 3 semester hours.

**MTGN542. ALLOYING THEORY, STRUCTURE, AND PHASE STABILITY. 3.0 Semester Hrs.**

(II) Empirical rules and theories relating to alloy formation. Various alloy phases and constituents which result when metals are alloyed and examined in detail. Current information on solid solutions, intermetallic compounds, eutectics, liquid immiscibility. Prerequisite: MTGN445 or none. 3 hours lecture; 3 semester hours.

**MTGN543. THEORY OF DISLOCATIONS. 3.0 Semester Hrs.**

(I) Stress field around dislocation, forces on dislocations, dislocation reactions, dislocation multiplication, image forces, interaction with point defects, interpretation of macroscopic behavior in light of dislocation mechanisms. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN544. FORGING AND DEFORMATION MODELING. 3.0 Semester Hrs.**

(I) Examination of the forging process for the fabrication of metal components. Techniques used to model deformation processes including slab equilibrium, slip line, upper bound and finite element methods. Application of these techniques to specific aspects of forging and metal forming processes. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN545. FATIGUE AND FRACTURE. 3.0 Semester Hrs.**

(I) Basic fracture mechanics as applied to engineering materials, S-N curves, the Goodman diagram, stress concentrations, residual stress effects, effect of material properties on mechanisms of crack propagation. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN546. CREEP AND HIGH TEMPERATURE MATERIALS. 3.0 Semester Hrs.**

(II) Mathematical description of creep process. Mathematical methods of extrapolation of creep data. Micromechanisms of creep deformation, including dislocation glide and grain boundary sliding. Study of various high temperature materials, including iron, nickel, and cobalt base alloys and refractory metals, and ceramics. Emphasis on phase transformations and microstructure-property relationships. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN547. PHASE EQUILIBRIA IN MATERIALS SYSTEMS. 3.0 Semester Hrs.**

(I) Phase equilibria of uniary, binary, ternary, and multicomponent systems, microstructure interpretation, pressure-temperature diagrams, determination of phase diagrams. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MTGN548. TRANSFORMATIONS IN METALS. 3.0 Semester Hrs.**

(I) Surface and interfacial phenomena, order of transformation, grain growth, recovery, recrystallization, solidification, phase transformation in solids, precipitation hardening, spinoidal decomposition, martensitic transformation, gas metal reactions. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN549. CURRENT DEVELOPMENTS IN FERROUS ALLOYS. 3.0 Semester Hrs.**

(I) Development and review of solid state transformations and strengthening mechanisms in ferrous alloys. Application of these principles to the development of new alloys and processes such as high strength low alloy steels, high temperature alloys, maraging steels, and case hardening processes. Prerequisite: MTGN348. 3 hours lecture; 3 semester hours.

**MTGN551. ADVANCED CORROSION ENGINEERING. 3.0 Semester Hrs.**

(I) Advanced topics in corrosion engineering. Case studies and industrial application. Special forms of corrosion. Advanced measurement techniques. Prerequisite: MTGN451. 3 hours lecture; 3 semester hours. (Fall of even years only.).

**MTGN552. INORGANIC MATRIX COMPOSITES. 3.0 Semester Hrs.**

Introduction to the processing, structure, properties and applications of metal matrix and ceramic matrix composites. Importance of structure and properties of both the matrix and the reinforcement and the types of reinforcement utilized-particulate, short fiber, continuous fiber, and laminates. Emphasis on the development of mechanical properties through control of synthesis and processing parameters. Other physical properties such as electrical and thermal will also be examined. Prerequisite/Co-requisite*: MTGN352, MTGN445/MLGN505*. 3 hours lecture; 3 semester hours. (Summer of even years only.).

**MTGN553. STRENGTHENING MECHANISMS. 3.0 Semester Hrs.**

(II) Strain hardening in polycrystalline materials, dislocation inter actions, effect of grain boundaries on strength, solid solution hardening, martensitic transformations, precipitation hardening, point defects. Prerequisite: MTGN543 or concurrent enrollment. 3 hours lecture;3 semester hours. (Spring of even years only.).

**MTGN554. OXIDATION OF METALS. 3.0 Semester Hrs.**

(II) Kinetics of oxidation. The nature of the oxide film. Transport in oxides. Mechanisms of oxidation. The Oxidation protection of hightemperature metal systems. Prerequisite:none. 3 hours lecture; 3 semester hours. (Spring of even years only.).

**MTGN555. SOLID STATE THERMODYNAMICS. 3.0 Semester Hrs.**

(I) Thermodynamics applied to solid state reactions, binary and ternary phase diagrams, point, line and planar defects, interfaces, and electrochemical concepts. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MTGN556. TRANSPORT IN SOLIDS. 3.0 Semester Hrs.**

(I) Thermal and electrical conductivity. Solid state diffusion in metals and metal systems. Kinetics of metallurgical reactions in the solid state. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of even years only.).

**MTGN557. SOLIDIFICATION. 3.0 Semester Hrs.**

(I) Heat flow and fluid flow in solidification, thermodynamics of solidification, nucleation and interface kinetics, grain refining, crystal and grain growth, constitutional supercooling, eutectic growth, solidification of castings and ingots, segregation, and porosity. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN560. ANALYSIS OF METALLURGICAL FAILURES. 3.0 Semester Hrs.**

(II) Applications of the principles of physical and mechanical metallurgy to the analysis of metallurgical failures. Nondestructive testing. Fractography. Case study analysis. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN561. PHYSICAL METALLURGY OF ALLOYS FOR AEROSPACE. 3.0 Semester Hrs.**

(I) Review of current developments in aerospace materials with particular attention paid to titanium alloys, aluminum alloys, and metal-matrix composites. Emphasis is on phase equilibria, phase transformations, and microstructure-property relationships. Concepts of innovative processing and microstructural alloy design are included where appropriate. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of even years only.).

**MTGN564. ADVANCED FORGING AND FORMING. 3.0 Semester Hrs.**

(II) Overview of plasticity. Examination and Analysis of working operations of forging, extrusion, rolling, wire drawing and sheet metal forming. Metallurgical structure evolution during working. Laboratory experiments involving metal forming processes. Prerequisites: MTGN445/MLGN505, 2 hours lecture; 3 hours lab, 3 semester hours.

**MTGN565. MECHANICAL PROPERTIES OF CERAMICS AND COMPOSITES. 3.0 Semester Hrs.**

(I) Mechanical properties of ceramics and ceramic-based composites; brittle fracture of solids; toughening mechanisms in composites; fatigue, high temperature mechanical behavior, including fracture, creep deformation. Prerequisites: MTGN445 or MLGN505. 3 hours lecture; 3 semester hours. (Fall of even years only.).

**MTGN569. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.**

Equivalent with CBEN569,MEGN569,MLGN569,

(I) Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical-thermodynamics and materials- science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. 3 credit hours.

**MTGN570. BIOCOMPATIBILITY OF MATERIALS. 3.0 Semester Hrs.**
Introduction to the diversity of biomaterials and applications through examination of the physiologic environment in conjunction with compositional and structural requirements of tissues and organs. Appropriate domains and applications of metals, ceramics and polymers, including implants, sensors, drug delivery, laboratory automation, and tissue engineering are presented. Prerequisites: BIOL110 or equivalent. 3 hours lecture; 3 semester hours.

**MTGN571. METALLURGICAL AND MATERIALS ENGINEERING LABORATORY. 1-3 Semester Hr.**
Basic instruction in advanced equipment and techniques in the field of extraction, mechanical or physical metallurgy. Prerequisite: Selection. 3 to 9 hours lab ; 1 to 3 semester hours.

**MTGN572. BIOMATERIALS. 3.0 Semester Hrs.**
Equivalent with MLGN572,
(I) A broad overview on materials science and engineering principles for biomedical applications with three main topics: 1) The fundamental properties of biomaterials; 2) The fundamental concepts in biology; 3) The interactions between biological systems with exogenous materials. Examples including surface energy and surface modification; protein adsorption; cell adhesion, spreading and migration; biomaterials implantation and acute inflammation; blood-materials interactions and thrombosis; biofilm and biomaterials-related pathological reactions. Basic principles of bio-mimetic materials synthesis and assembly will also be introduced. 3 hours lecture; 3 semester hours.

**MTGN573. COMPUTATIONAL MATERIALS. 3.0 Semester Hrs.**
(II) Computational Materials is a course designed as an introduction to computational approaches and codes used in modern materials science and engineering, and to provide the hands?on experience in using massively parallel supercomputers and popular materials software packages. The main goal is to provide exposure to students to the growing and highly interdisciplinary field of computational materials science and engineering, through a combination of lectures, hands-on exercises and a series of specifically designed projects. The course is organized to cover different length scales including: atomistic (electronic structure) calculations, molecular dynamics, and phase equilibria modeling. The emerging trends in data driven materials discovery and design are also covered. Particular emphasis is placed on the validation of computational results and recent trends in integrating theory, computations and experiment. Graduate students are expected to successfully complete 4 projects while the undergraduate students are required to finish 3 out of 4 projects. 3 hours lecture; 3 semester hours.

**MTGN580. ADVANCED WELDING METALLURGY. 3.0 Semester Hrs.**
(II) Weldability of high strength steels, high alloys, and light metals; Welding defects; Phase transformations in weldments; Thermal experience in weldments; Pre- and Post-weld heat treatment; Heat affected zone formation, microstructure, and properties; Consumables development. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN581. WELDING HEAT SOURCES AND INTERACTIVE CONTROLS. 3.0 Semester Hrs.**
(I) The science of welding heat sources including gas tungsten arc, gas metal arc, electron beam and laser. The interaction of the heat source with the workpiece will be explored and special emphasis will be given to using this knowledge for automatic control of the welding process. Prerequisite: Graduate Status. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN582. MECHANICAL PROPERTIES OF WELDED JOINTS. 3.0 Semester Hrs.**
(II) Mechanical metallurgy of heterogeneous systems, shrinkage, distortion, cracking, residual stresses, mechanical testing of joints, size effects, joint design, transition temperature, fracture. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN583. PRINCIPLES OF NON-DESTRUCTIVE TESTING AND EVALUATION. 3.0 Semester Hrs.**
(I) Introduction to testing methods; basic physical principles of acoustics, radiography, and electromagnetism; statistical and risk analysis; fracture mechanics concepts; design decision making, limitations and applications of processes; fitness-for- service evaluations. Prerequisite: Graduate Status. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN584. NON-FUSION JOINING PROCESSES. 3.0 Semester Hrs.**
(II) Joining processes for which the base materials are not melted. Brazing, soldering, diffusion bonding, explosive bonding, and adhesive bonding processes. Theoretical aspects of these processes, as well as the influence of process parameters. Special emphasis to the joining of dissimilar materials using these processes. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of even years only.).

**MTGN586. DESIGN OF WELDED STRUCTURES AND ASSEMBLIES. 3.0 Semester Hrs.**
Introduction to the concepts and analytical practice of designing weldments. Designing for impact, fatigue, and torsional loading. Designing of weldments using overmatching and undermatching criteria. Analysis of combined stresses. Designing of compression members, column bases and splices. Designing of built-up columns, welded plate cylinders, beam-to-column connections, and trusses. Designing for tubular construction. Weld distortion and residual stresses. Joint design. Process consideration in weld design. Welding codes and specifications. Estimation of welding costs. Prerequisite/Co-requisite: MATH225 or equivalent, EGGN320 or equivalent, MTGN475. 3 hours lecture; 3 semester hours. (Summer of odd years only.).

**MTGN587. PHYSICAL PHENOMENA OF WELDING AND JOINING PROCESSES. 3.0 Semester Hrs.**
(I) Introduction to arc physics, fluid flow in the plasma, behavior of high pressure plasma, cathodic and anodic phenomena, energy generation and temperature distribution in the plasma, arc stability, metal transfer across arc, electron beam welding processes, keyhole phenomena. Ohmic welding processes, high frequency welding, weld pool phenomena. Development of relationships between physics concepts and the behavior of specific welding and joining processes. Prerequisite/Co-requisite: PHGN300, MATH225, MTGN475. 3 hours lecture; 3 semester hours. (Fall of even years only.).

**MTGN591. PHYSICAL PHENOMENA OF COATING PROCESSES. 3.0 Semester Hrs.**
(I) Introduction to plasma physics, behavior of low pressure plasma, cathodic and anodic phenomena, glow discharge phenomena, glow discharge sputtering, magnetron plasma deposition, ion beam deposition, cathodic arc evaporation, electron beam and laser coating processes. Development of relationships between physics concepts and the behavior of specific coating processes. Prerequisite/ Co-requisite: PHGN300, MATH225. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN593. NUCLEAR MATERIALS SCIENCE AND ENGINEERING. 3.0 Semester Hrs.**

(I) Introduction to the physical metallurgy of nuclear materials, including the nuclear, physical, thermal, and mechanical properties for nuclear materials, the physical and mechanical processing of nuclear alloys, the effect of nuclear and thermal environments on structural reactor materials and the selection of nuclear and reactor structural materials are described. Selected topics include ceramic science of ceramic nuclear material, ceramic processing of ceramic fuel, nuclear reaction with structural materials, radiation interactions with materials, the aging of nuclear materials, cladding, corrosion and the manufacturing of fuels elements. Relevant issues in the modern fuel cycle will also be introduced including nuclear safety, reactor decommissioning, and environmental impacts. Prerequisites: Graduate or Senior in good-standing. 3 hours lecture, 3 semester hours. (Fall of even years only.).

**MTGN598. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 6.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**MTGN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**

(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**MTGN605. ADVANCED TRANSMISSION ELECTRON MICROSCOPY. 2.0 Semester Hrs.**

Introduction to transmission electron microscopy techniques and their application to materials characterization. Topics include electron optics, electron-specimen interactions, imaging, diffraction, contrast mechanisms, defect analyses, compositional measurements using energy dispersive x-ray spectroscopy and energy loss spectroscopy, scanning transmission electron microscopy, high angle annular dark field imaging, energy filtered TEM and high resolution phase contrast imaging. Prerequisite: MTGN 505. Co-requisite; MTGN 605L. 2 hours lecture, 2 semester hours.

**MTGN605L. ADVANCED TRANSMISSION ELECTRON MICROSCOPY LABORATORY. 1.0 Semester Hr.**

Specimen preparation techniques and their application to materials characterization. Topics include electron optics, electron-specimen interactions, imaging, diffraction, contrast mechanisms, defect analyses, compositional measurements using energy dispersive x-ray spectroscopy and energy loss spectroscopy, scanning transmission electron microscopy, high angle annular dark field imaging, energy filtered TEM and high resolution phase contrast imaging. Prerequisite: Concurrent enrollment in MTGN 605. 3 hours lab, 1 semester hour.

**MTGN631. TRANSPORT PHENOMENA IN METALLURGICAL AND MATERIALS SYSTEMS. 3.0 Semester Hrs.**

Physical principles of mass, momentum, and energy transport. Application to the analysis of extraction metallurgy and other physicochemical processes. Prerequisite: MATH225 and MTGN461 or equivalent. 3 hours lecture; 3 semester hours.

**MTGN671. ADVANCED MATERIALS LABORATORY. 1-3 Semester Hr.**

(I) Experimental and analytical research in the fields of production, mechanical, chemical, and/or physical metallurgy. Prerequisite: none. 1 to 3 semester hours; 3 semester hours.

**MTGN672. ADVANCED MATERIALS LABORATORY. 1-3 Semester Hr.**

(II) Continuation of MTGN671. 1 to 3 semester hours.

**MTGN696. VAPOR DEPOSITION PROCESSES. 3.0 Semester Hrs.**

(II) Introduction to the fundamental physics and chemistry underlying the control of deposition processes for thin films for a variety of applications? wear resistance, corrosion/oxidation resistance, decorative coatings, electronic and magnetic. Emphasis on the vapor deposition process varia - bles rather than the structure and properties of the deposited film. Prerequisites: MTGN351, MTGN461, or equivalent courses. 3 hours lecture; 3 semester hours. (Summer of odd years only.).

**MTGN697. MICROSTRUCTURAL EVOLUTION OF COATINGS AND THIN FILMS. 3.0 Semester Hrs.**

(I) Introduction to aqueous and non-aqueous chemistry for the preparation of an effective electrolyte; for interpretation of electrochemical principles associated with electrodeposition; surface science to describe surface structure and transport; interphasial structure including space charge and double layer concepts; nucleation concepts applied to electrodeposition; electrocrystallization including growth concepts; factors affecting morphology and kinetics; co-deposition of non-Brownian particles; pulse electrodeposition; electrodeposition parameters and control; physical metallurgy of electrodeposits; and, principles associated with vacuum evaporation and sputter deposition. Factors affecting microstructural evolution of vacuum and sputtered deposits; nucleation of vapor and sputtered deposits; modeling of matter-energy interactions during co-deposition; and, Thornton?s model for coating growth. Prerequisite/ co-requisite: MATH225, MTGN351, MTGN352. 3 hours lecture; 3 semester hours. (Summer of even years only.).

**MTGN698. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 6.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**MTGN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**

(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**MTGN700. GRADUATE RESEARCH CREDIT: MASTER OF ENGINEERING. 1-6 Semester Hr.**

(I, II, S) Research credit hours required for completion of the degree Master of Engineering. Research under the direct supervision of a faculty advisor. Credit is not transferable to any 400, 500, or 600 level courses. However, MTGN 705 credit hours may be transferred, in accordance with the requirements for this (M.E.) degree, by a Master of Science graduate-student who previously accumulated these credit-hours and subsequently opted to change their degree program to a Master of Engineering. Repeatable for credit. Variable: 1 to 6 semester hours.

**MTGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

## Professors

Kip O. Findley

Michael J. Kaufman, Vice Provost, Graduate Initiatives and Dean of Materials and Energy Programs

Ryan O'Hayre

Ivar E. Reimanis, Herman F. Coors Distinguished Professor of Ceramics

Angus Rockett, Department Head

Sridhar Seetharaman

John G. Speer, American Bureau of Shipping Endowed Chair in Metallurgical and Materials Engineering

## Associate Professors

Geoff L. Brennecka, Assistant Director, Materials Science, Fryrear Chair for Innovation and Excellence

Amy Clarke

Emmanuel De Moor

Brian Gorman

Jeffrey C. King

Corinne E. Packard

## Assistant Professors

Kester Clarke, FIERF Professor

Vladan Stevanovic

Zhenzhen Yu

## Teaching Professor

Gerald Bourne, Assistant Department Head

## Research Professors

Ivan Cornejo

Robert Field

Terry Lowe

Stephen Midson

## Research Associate Professor

Robert Cryderman

## Research Assistant Professors

David Diercks

Judith C. Gomez

Juan Carlos Madeni

Michael Sanders

## Professors Emeriti

Glen R. Edwards, University Professor Emeritus

John P. Hager, University Professor Emeritus

George Krauss, University Professor Emeritus

Stephen Liu, University Professor Emeritus, Inaugural American Bureau of Shipping Chair Professor

Gerard P. Martins, Professor Emeritus

David K. Matlock, University Professor Emeritus

Brajendra Mishra, University Professor Emeritus

John J. Moore, Professor Emeritus

David L. Olson, University Professor Emeritus

Dennis W. Readey, University Professor Emeritus

Chester J. Van Tyne, Professor Emeritus

## Associate Professors Emeriti

Gerald L. DePoorter

Robert H. Frost

Steven W. Thompson

## Affiliate Faculty

Richard K. Ahrenkiel

Corby G. Anderson

Patrick R. Taylor, George S. Ansell Distinguished Professor of Chemical Metallurgy

Edgar Vidal

James C. Williams

## Research Associates

Carole Graas

Gary Zito

# Mining Engineering

## Degrees Offered

- Master of Science in Mining Engineering (Thesis or Non-Thesis)
- Doctor of Philosophy in Mining Engineering
- Master of Science in Earth Resource Development Engineering (Thesis or Non-Thesis)
- Doctor of Philosophy in Earth Resource Development Engineering
- Professional Masters in Mining Engineering and Management

## Program Description

The program has two distinctive, but inherently interwoven specialties.

The **Mining Engineering** area or specialty is predominantly for mining engineers and it is directed towards the traditional mining engineering fields. Graduate work is normally centered around subject areas such as mine planning and development, computer aided mine design, rock mechanics, operations research applied to the mineral industry, environment and sustainability considerations, mine mechanization, mine evaluation, finance and management and similar mining engineering topics.

The **Earth Resources Development Engineering** specialty is for those who wish to specialize in interdisciplinary fields that include understanding emerging technical and social issues in Earth Resources Development Engineering. This specialty is open to students with mining or non-mining engineering undergraduate degrees who are interested in scholarship and research on topics including, but not limited to, mining and sustainability, mine closure and reclamation engineering, corporate social responsibility, artisanal and small-scale mining, underground construction and tunneling engineering, mining and the environment, modeling and design in earth systems and processes, geothermal, explosive engineering, mine and construction management, mining-related data science, earth observation for mine environmental monitoring and design and application of sensor networks, Internet of Things (IoT), robotics and Artificial Intelligence (AI) for autonomous mine systems. Because of the interdisciplinary nature of this degree program, students will be required to take three core classes in the Mining Engineering Department and then choose courses related to their area of interest offered by mining, as well as other departments across campus.

Graduate work is normally centered around subject areas such as site characterization, environmental aspects, underground construction and tunneling (including microtunneling), excavation methods and equipment, mechanization of mines and underground construction, environmental and management aspects, modeling and design in geoengineering.

Mining Engineering Program Description

Regarding academics and research the Mining Engineering Department focuses on fundamental areas including:

- Geomechanics, rock mechanics and stability of underground and surface excavations
- Computerized mine design and related applications (including geostatistical modeling)
- Advanced integrated mining systems incorporating mine mechanization and mechanical mining systems
- Underground excavation, tunneling and construction
- Construction and project management
- Site characterization and geotechnical investigations, modeling and design in geoengineering
- Rock fragmentation
- Mineral processing, comminution and separation technology
- Bulk material handling
- Mine ventilation
- Mine safety and health
- Corporate Social Responsibility and Sustainability
- Artisanal and Small-Scale Mining

## Program Requirements

The Master of Science degree in Mining Engineering has two options available, Thesis and Non-Thesis.

For the PhD degree, students holding an MS degree in an appropriate field may transfer, with the approval of the Graduate Advisor and the Doctoral Committee, a maximum of 30 credit hours of graduate course work towards the credit hours to be completed for the PhD. The doctoral dissertation must be successfully defended before the approved Doctoral Committee.

## Mining Engineering (MNEG) Degree Requirements

## Master of Science - Thesis (MS-T)

Students in the Mining Engineering MS-T degree program must take a minimum of 12 course credit hours of the 21 credit hour requirement from within the Mining Engineering Department. These must include the core requirement courses listed below, unless waived by the Master's Thesis Committee.

| | |
|---|---|
| Course work credits (minimum) | 21.0 |
| Research credits (maximum) | 9.0 |
| **Total credits (minimum)** | 30.0 |

## Master of Science - Non-thesis (MS-NT)

Students in the Mining Engineering MS-NT program must take a minimum of 21 credit hours of course work from within Mining Engineering Department. These must include the core requirement courses listed below unless waived. A maximum of 9 semester hours of 400 level courses can be applied to the credit hours required.

| | |
|---|---|
| **Total course work credits (minimum)** | 30.0 |

## Mines' Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any 400+ level courses that count towards the undergraduate degree requirements as "Elective Coursework" or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a "B-" or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

## Doctor of Philosophy

Maximum of 48 semester credit hours of course work is required. A maximum of 30 units can be transferred from a MS degree program. The student's Graduate Committee must approve the transfer of these units. A minimum of 18 credit course hours must be taken in the Mining Engineering Department. A maximum of 9 semester hours of 400 level courses can be applied to the credit hours required.

| | |
|---|---|
| Course work credits (minimum) | 48.0 |
| Research credits (minimum) | 24.0 |
| **Credit hours beyond the BS degree (required)** | 72.0 |

## Other PhD Requirements

- A minimum of 18 hours of course work must be completed at the Colorado School of Mines. A minimum of 9 credits beyond the Master's degree must be completed in the Mining Engineering Department. Exceptions may be approved by the PhD Dissertation Committee.
- Those with an MS in an appropriate field may transfer a maximum of 30 credit hours of course work towards the course work requirement, subject to the approval by the Advisor and Doctoral Committee.
- The doctoral dissertation thesis must be successfully defended before the Doctoral Committee.
- Assessment Exam, usually taken at the end of the first year in the PhD program.
- Minimum GPA requirement: 3.0/4.0.
- Thesis Proposal Approval.
- Comprehensive Exams, oral mandatory, written may be waived at the discretion of the Doctoral Committee.

## Required Core Courses for either the MS or PhD degree:

Two of the following three graduate courses are required to be completed to receive a Mining Engineering graduate degree at Mines:

| | | |
|---|---|---|
| MNGN508 | ADVANCED ROCK MECHANICS | 3.0 |
| MNGN512 | SURFACE MINE DESIGN | 3.0 |
| MNGN516 | UNDERGROUND MINE DESIGN | 3.0 |

## Prerequisites

Students entering the Mining Engineering graduate program for either the master's or doctoral degree are expected to have completed an undergraduate ABET-accredited BS degree in Mining Engineering. Deficiencies, if any, will be determined by the Department of Mining Engineering on the basis of a student's academic record and experience. For specific information on prerequisites, students are encouraged to refer to the Mining Engineering Department's Graduate Handbook, available from the Department of Mining Engineering or on the web site at https://mining.mines.edu/graduate-program/.

## Earth Resources Development Engineering Program Description

The Earth Resources Development Engineering specialty is for those who wish to specialize in interdisciplinary fields that include understanding emerging technical and social issues in Earth Resources Development Engineering. This specialty is open to students with mining or non-mining engineering undergraduate degrees who are interested in scholarship and research on topics including, but not limited to, mining and sustainability, mine closure and reclamation engineering, corporate social responsibility, artisanal and small-scale mining, underground construction and tunneling engineering, mining and the environment, modeling and design in earth systems and processes, geothermal, explosive engineering, mine and construction management, mining related data science, earth observation for mine environmental monitoring and design and application of sensor networks, Internet of Things (IoT), robotics and Artificial Intelligence (AI) for autonomous mine systems. Because of the interdisciplinary nature of this degree program, students will be required to take three core classes in the Mining Engineering Department and then choose courses related to their area of interest offered by mining, as well as other departments across campus.

The Master of Science in Earth Resources Development Engineering has two MS degree options (thesis and non-thesis). For the PhD degree, students holding an MS degree in a relevant field may transfer, with the approval of the doctoral committee, a maximum of 30 credit hours of graduate course work towards the required credit hours for the PhD degree. The doctoral dissertation must be successfully defended before the approved doctoral committee.

## Earth Resource Development Engineering (ERDE) Degree Requirements

## Master of Science - Thesis (MS-T)

Students in the ERDE MS-T program must take a minimum of 15 credit hours from within the Mining Engineering Department. These must include the required core courses listed below unless waived by the Master's Thesis Committee.

| | |
|---|---|
| Course work credits (minimum) | 21.0 |
| Research credits (maximum) | 9.0 |
| **Total credits (minimum)** | 30.0 |

## Master of Science - Non-Thesis (MS-NT)

Students in the ERDE MS-NT program must take a minimum of 15 credit hours of course work from within Mining Engineering Department. These must include the required core courses listed below unless waived. A maximum of 9 semester hours of 400 level courses can be applied to the course credit hours required.

| | |
|---|---|
| **Total course work credits (minimum)** | 30.0 |

## Mines' Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any 400+ level courses that count towards the undergraduate degree requirements as "Elective Coursework" or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a "B-" or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

## Doctor of Philosophy

Maximum of 48 semester credit hours of course work, where a maximum of 30 units can be transferred from a M.S. degree program. The student's Graduate committee must approve the transfer of these units. A minimum of 9 credit course hours must be taken in the Mining Engineering Department. These must include the required core courses listed below unless waived. A maximum of 9 semester hours of 400 level courses can be applied to the credit hours required.

| | |
|---|---|
| Course work credits (minimum) | 48.0 |
| Research credits (minimum) | 24.0 |
| **Credit hours beyond the BS degree (required)** | 72.0 |

## Other PhD Requirements

- A minimum of 18 hours of course work must be completed at the Colorado School of Mines. A minimum of 9 credits beyond the Master's degree must be completed in the Mining Engineering Department. Exceptions may be approved by the PhD Dissertation Committee.
- Those with an MS in an appropriate field may transfer a maximum of 30 credit hours of course work towards the course work requirement, subject to the approval by the Advisor and doctoral committee.
- The doctoral dissertation thesis must be successfully defended before the doctoral committee.
- Assessment Exam, usually taken at the end of the first year in the PhD program.
- Minimum GPA requirement: 3.0/4.0.
- Thesis Proposal Approval.
- Comprehensive Exams, oral mandatory, written may be waived at the discretion of the Doctoral Committee.

## Required Core Courses for either the MS or PhD degree:

***The following course is required:***

| | | |
|---|---|---|
| MNGN510 | FUNDAMENTALS OF MINING AND MINERAL RESOURCE DEVELOPMENT | 3.0 |

***In addition, two of the following four courses are required:***

| | | |
|---|---|---|
| MNGN5XX | Sustainable Development and Earth Resources | 3.0 |
| MNGN556 | MINE WATER AND ENVIRONMENT | 3.0 |
| MNGN5XX | Big Data Analytics for Earth Resources Sciences and Engineering | 3.0 |
| MNGN528 | MINING GEOLOGY | 3.0 |

## Prerequisites

Students entering the ERDE graduate program for either the master's or doctoral degree are expected to have completed the equivalent of an undergraduate ABET-accredited BS degree in some discipline of engineering. Deficiencies, if any, will be determined by the Department of Mining Engineering on the basis of a student's academic record and experience. For specific information on prerequisites, students are encouraged to refer to the Mining Engineering Department's Graduate Handbook, available from the Department of Mining Engineering or on the web site at https://mining.mines.edu/graduate-program/.

## Professional Masters in Mining Engineering and Management Program Description and Degree Requirements

The PM in Mining Engineering and Management is a unique and competitive degree offering that stands alone among graduate mining engineering programs at domestic and international institutions. This new degree does not replace existing graduate programs that focus on technical development and research, but provides a unique choice for students with managerial and business aspirations to obtain an advanced education in the mining and mineral industries. The PM is a fully online graduate program. It is not offered on campus. It is open to anyone who has an engineering degree plus at least five years of experience in the mining sector. There is no premium cost for students who reside outside Colorado or outside the United States. This program does not require students to ever travel to the Mines campus. Students accepted into the program join a cohort, which cohort will take all the program courses in sequence over a two-year period. See https://mining.mines.edu/professionalmasters/ for more information. Online delivery will give the program a competitive edge by offering the flexible schedule necessary to attract professionals in full-time employment, or others that cannot leave their place of residence.

The PM curriculum content was developed by Mining Engineering faculty based on discussions with the Department's Industry Advisory Committee, education professionals, and members of the mining industry.

The curriculum includes 12 courses and one independent project, encompassing 33 credit hours (CR). Course content is guided by the vision and values of Mines and the Mining Engineering Department.

The following PM courses are specifically reserved for students enrolled in the online Professional Masters in Mining Engineering and Management program. If a student would like to take a particular PM course and is not enrolled in this program, they should send an email to PM-MEM@mines.edu requesting approval to take the course, as acceptance into the course will be based on capacity and faculty willingness to accept additional students.

| | | |
|---|---|---|
| MNGN553 | MINE DESIGN AND OPERATION PLANNING | 3.0 |
| MNGN548 | INTEGRATED INFORMATION AND MINE SYSTEMS MANAGEMENT | 3.0 |
| MNGN547 | GEOLOGY AND MINING | 3.0 |
| MNGN558 | MINERAL PROCESSING | 3.0 |
| MNGN546 | MINE HEALTH AND SAFETY | 2.0 |
| MNGN562 | MINING ENVIRONMENTAL AND SOCIAL RESPONSIBILITY | 2.0 |
| MNGN563 | WATER WASTE AND MINE CLOSURE | 3.0 |
| MNGN551 | MINE ACCOUNTING | 2.0 |
| MNGN554 | MINE FINANCE | 2.0 |
| MNGN557 | MINERAL ECONOMICS AND POLICY | 2.0 |
| MNGN561 | PROJECT MANAGEMENT | 3.0 |
| MNGN555 | MINE INVESTMENT EVALUATION | 3.0 |
| MNGN 5XX | INDEPENDENT PROJECT | 2.0 |
| Total Semester Hrs | | 33.0 |

The program is developed to meet the world's evolving challenges related to the Earth, Energy and the Environment, and to address the needs of the world's growing population to recover and conserve the Earth's resources. The curriculum will confirm the Colorado School of Mines as an internationally recognized leader in engineering education by providing a unique educational experience that collaborates with industry to prepare graduates for leadership in the earth resources industries.

Based on the Faculty's assessment of the changes in emerging technical, social, and economic factors present in developing a mineral resource, the proposed Colorado School of Mines curriculum will be the product of choice for domestic and international professional education for the mining industry.

## Courses

**MNGN501. REGULATORY MINING LAWS AND CONTRACTS. 3.0 Semester Hrs.**
(I) Basic fundamentals of engineering law, regulations of federal and state laws pertaining to the mineral industry and environment control. Basic concepts of mining contracts. Offered in even numbered years. Prerequisite: Senior or graduate status. 3 hours lecture; 3 semester hours. Offered in even years.

**MNGN503. MINING TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT. 3.0 Semester Hrs.**
(I, II) The primary focus of this course is to provide students an understanding of the fundamental principles of sustainability and how they influence the technical components of a mine's life cycle, beginning during project feasibility and extending through operations to closure and site reclamation. Course discussions will address a wide range of traditional engineering topics that have specific relevance and impact to local and regional communities, such as mining methods and systems, mine plant design and layout, mine operations and supervision, resource utilization and cutoff grades, and labor. The course will emphasize the importance of integrating social, political, and economic considerations into technical decision-making and problem solving. 3 hours lecture; 3 semester hours.

**MNGN504. UNDERGROUND CONSTRUCTION ENGINEERING IN HARD ROCK. 3.0 Semester Hrs.**
(II) This course is developed to introduce students to the integrated science, engineering, design and management concepts of engineered underground construction. The course will cover advanced rock engineering in application to underground construction, geological interpretation and subsurface investigations, equipment options and system selection for projects with realistic constraints, underground excavation initial support and final shotcrete/lining design, and approaches to uncertainty evaluation and risk assessment for underground construction projects. Team design projects and presentations will be required. Prerequisites: CEEN513. Co-requisites: GEGN562. 3 hours lecture; 3 semester hours.

**MNGN505. ROCK MECHANICS IN MINING. 3.0 Semester Hrs.**
(I) The course deals with the rock mechanics aspect of design of mine layouts developed in both underground and surface. Underground mining sections include design of coal and hard rock pillars, mine layout design for tabular and massive ore bodies, assessment of caving characteristics or ore bodies, performance and application of backfill, and phenomenon of rock burst and its alleviation. Surface mining portion covers rock mass characterization, failure modes of slopes excavated in rock masses, probabilistic and deterministic approaches to design of slopes, and remedial measures for slope stability problems. Prerequisite: MN321 or equivalent. 3 hours lecture; 3 semester hours.

**MNGN506. DESIGN AND SUPPORT OF UNDERGROUND EXCAVATIONS. 3.0 Semester Hrs.**
Design of underground excavations and support. Analysis of stress and rock mass deformations around excavations using analytical and numerical methods. Collections, preparation, and evaluation of insitu and laboratory data for excavation design. Use of rock mass rating systems for site characterization and excavation design. Study of support types and selection of support for underground excavations. Use of numerical models for design of shafts, tunnels and large chambers. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered in odd years.

**MNGN507. ADVANCED DRILLING AND BLASTING. 3.0 Semester Hrs.**
(I) An advanced study of the theories of rock penetration including percussion, rotary, and rotary percussion drilling. Rock fragmentation including explosives and the theories of blasting rock. Application of theory to drilling and blasting practice at mines, pits, and quarries. Prerequisite: MNGN407. 3 hours lecture; 3 semester hours. Offered in odd years.

**MNGN508. ADVANCED ROCK MECHANICS. 3.0 Semester Hrs.**
Equivalent with MNGN418,
(I, II, S) Analytical and numerical modeling analysis of stresses and displacements induced around engineering excavations in rock. Insitu stress. Rock failure criteria. Complete load deformation behavior of rocks. Measurement and monitoring techniques in rock mechanics. Principles of design of excavation in rocks. Analytical, numerical modeling and empirical design methods. Probabilistic and deterministic approaches to rock engineering designs. Excavation design examples for shafts, tunnels, large chambers and mine pillars. Seismic loading of structures in rock. Phenomenon of rock burst and its alleviation. One additional design project will be assigned to graduate students. Prerequisites: MNGN321. 3 hours lecture; 3 semester hours.

**MNGN509. CONSTRUCTION ENGINEERING AND MANAGEMENT. 3.0 Semester Hrs.**
Equivalent with GOGN506,
(II) The course will provide content, methods and experience in construction planning and cost estimating, scheduling and equipment performance, contractual delivery systems and relationships, key contract clauses, risk registration and management, and project controls. Special attention will be paid to geotechnical uncertainty and risk, emerging technologies and industry trends, and to ethics and sustainability as applied to construction engineering and management practices. Co-requisites: GEGN562. 3 hours lecture; 3 semester hours.

**MNGN510. FUNDAMENTALS OF MINING AND MINERAL RESOURCE DEVELOPMENT. 3.0 Semester Hrs.**
Specifically designed for non-majors, the primary focus of this course is to provide students with a fundamental understanding of how mineral resources are found, developed, mined, and ultimately reclaimed. The course will present a wide range of traditional engineering and economic topics related to: exploration and resource characterization, project feasibility, mining methods and systems, mine plant design and layout, mine operations and scheduling, labor, and environmental and safety considerations. The course will emphasize the importance of integrating social (human), political, and environmental issues into technical decision-making and design. 3 hours lecture; 3 semester hours.

**MNGN511. MINING INVESTIGATIONS. 2-4 Semester Hr.**
(I, II) Investigational problems associated with any important aspect of mining. Choice of problem is arranged between student and instructor. Prerequisite: none. Lecture, consultation, lab, and assigned reading; 2 to 4 semester hours.

**MNGN512. SURFACE MINE DESIGN. 3.0 Semester Hrs.**
Analysis of elements of surface mine operation and design of surface mining system components with emphasis on minimization of adverse environmental impact and maximization of efficient use of mineral resources. Ore estimates, unit operations, equipment selection, final pit determinations, short- and long-range planning, road layouts, dump planning, and cost estimation. Prerequisite: MNGN210. 3 hours lecture; 3 semester hours.

**MNGN514. MINING ROBOTICS. 3.0 Semester Hrs.**
(I) Fundamentals of robotics as applied to the mining industry. The focus is on mobile robotic vehicles. Topics covered are mining applications, introduction and history of mobile robotics, sensors, including vision, problems of sensing variations in rock properties, problems of representing human knowledge in control systems, machine condition diagnostics, kinematics, and path finding. Prerequisite: CSCI404. 3 hours lecture; 3 semester hours. Offered in odd years.

**MNGN515. MINE MECHANIZATION AND AUTOMATION. 3.0 Semester Hrs.**
This course will provide an in-depth study of the current state of the art and future trends in mine mechanization and mine automation systems for both surface and underground mining, review the infrastructure required to support mine automation, and analyze the potential economic and health and safety benefits. Prerequisite: MNGN312, MNGN314, MNGN316. 2 hours lecture, 3 hours lab; 3 semester hours. Fall of odd years.

**MNGN516. UNDERGROUND MINE DESIGN. 3.0 Semester Hrs.**
Selection, design, and development of most suitable underground mining methods based upon the physical and the geological properties of mineral deposits (metallics and nonmetallics), conservation considerations, and associated environmental impacts. Reserve estimates, development and production planning, engineering drawings for development and extraction, underground haulage systems, and cost estimates. Prerequisite: MNGN210. 2 hours lecture, 3 hours lab; 3 semester hours.

**MNGN517. ADVANCED UNDERGROUND MINING. 3.0 Semester Hrs.**
(II) Review and evaluation of new developments in advanced underground mining systems to achieve improved productivity and reduced costs. The major topics covered include: mechanical excavation techniques for mine development and production, new haulage and vertical conveyance systems, advanced ground support and roof control methods, mine automation and monitoring, new mining systems and future trends in automated, high productivity mining schemes. Prerequisite: Underground Mine Design (e.g., MNGN314). 3 hours lecture; 3 semester hours.

**MNGN518. ADVANCED BULK UNDERGROUND MINING TECHNIQUES. 3.0 Semester Hrs.**
This course will provide advanced knowledge and understanding of the current state-of-the-art in design, development, and production in underground hard rock mining using bulk-mining methods. Design and layout of sublevel caving, block caving, open stoping and blasthole stoping systems. Equipment selection, production scheduling, ventilation design, and mining costs. Prerequisites: MNGN314, MNGN516. 2 hours lecture, 3 hours lab; 3 semester hours. Spring of odd years.

**MNGN519. ADVANCED SURFACE COAL MINE DESIGN. 3.0 Semester Hrs.**
(II) Review of current manual and computer methods of reserve estimation, mine design, equipment selection, and mine planning and scheduling. Course includes design of a surface coal mine for a given case study and comparison of manual and computer results. Prerequisite: MNGN312, 316, 427. 2 hours lecture, 3 hours lab; 3 semester hours. Offered in odd years.

**MNGN520. ROCK MECHANICS IN UNDERGROUND COAL MINING. 3.0 Semester Hrs.**
(I) Rock mechanics consideration in the design of room-and-pillar, longwall, and shortwall coal mining systems. Evaluation of bump and outburst conditions and remedial measures. Methane drainage systems. Surface subsidence evaluation. Prerequisite: MNGN321. 3 hours lecture; 3 semester hours. Offered in odd years.

**MNGN522. FLOTATION. 3.0 Semester Hrs.**
Science and engineering governing the practice of mineral concentration by flotation. Interfacial phenomena, flotation reagents, mineral-reagent interactions, and zeta-potential are covered. Flotation circuit design and evaluation as well as tailings handling are also covered. The course also includes laboratory demonstrations of some fundamental concepts. 3 hours lecture; 3 semester hours.

**MNGN523. SELECTED TOPICS. 2-4 Semester Hr.**
(I, II) Special topics in mining engineering, incorporating lectures, laboratory work or independent study, depending on needs. This course may be repeated for additional credit only if subject material is different. Prerequisite: none. 2 to 4 semester hours. Repeatable for credit under different titles.

**MNGN524. ADVANCED MINE VENTILATION. 3.0 Semester Hrs.**
(I) Advanced topics of mine ventilation including specific ventilation designs for various mining methods, ventilation numerical modeling, mine atmosphere management, mine air cooling, prevention and ventilation response to mine fires and explosions, mine dust control. Prerequisites: MNGN424 Mine Ventilation. Lecture and Lab Contact Hours: 3 hours lecture; 3 semester credit hours.

**MNGN525. INTRODUCTION TO NUMERICAL TECHNIQUES IN ROCK MECHANICS. 3.0 Semester Hrs.**
(I) Principles of stress and infinitesimal strain analysis are summarized, linear constitutive laws and energy methods are reviewed. Continuous and laminated models of stratified rock masses are introduced.
The general concepts of the boundary element and finite element methods are discussed. Emphasis is placed on the boundary element approach with displacement discontinui ties, because of its relevance to the modeling of the extraction of tabular mineral bodies and to the mobilization of faults, joints, etc. Several practical problems, selected from rock mechanics and subsidence engineering practices, are treated to demonstrate applications of the techniques. Prerequi site: MNGN321, EGGN320, or equivalent courses, MATH455. 3 hours lecture; 3 semester hours. Offered in even years.

**MNGN526. MODELING AND MEASURING IN GEOMECHANICS. 3.0 Semester Hrs.**

(II) Introduction to instruments and instrumen tation systems used for making field measurements (stress, convergence, deformation, load, etc.) in geomechanics. Techniques for determining rock mass strength and deformability. Design of field measurement programs. Interpretation of field data. Development of predictive models using field data. Intro duction to various numerical techniques (boundary element, finite element, FLAC, etc.) for modeling the behavior of rock structures. Demonstration of concepts using various case studies. Prerequisite: Graduate standing. 2 hours lecture, 3 hours lab; 3 semester hours. Offered in odd years.

**MNGN527. THEORY OF PLATES AND SHELLS. 3.0 Semester Hrs.**

Classical methods for the analysis of stresses in plate type structure are presented first. The stiffness matrices for plate element will be developed and used in the finite element method of analysis. Membrane and bending stresses in shells are derived. Application of the theory to tunnels, pipes, pressures vessels, and domes, etc., will be included. Prerequisites: EGGN320. 3 hours lecture; 3 credit hours.

**MNGN528. MINING GEOLOGY. 3.0 Semester Hrs.**

(I) Role of geology and the geologist in the development and production stages of a mining operation. Topics addressed: mining operation sequence, mine mapping, drilling, sampling, reserve estimation, economic evaluation, permitting, support functions. Field trips, mine mapping, data evaluation, exercises and term project. Prerequisite: GEGN401 or GEGN405. 2 hours lecture/seminar, 3 hours laboratory: 3 semester hours. Offered in even years.

**MNGN529. URANIUM MINING. 2.0 Semester Hrs.**

(I) Overview and introduction to the principles of uranium resource extraction and production. All aspects of the uranium fuel cycle are covered, including the geology of uranium, exploration for uranium deposits, mining, processing, environmental issues, and health and safety aspects. A lesser emphasis will be placed on nuclear fuel fabrication, nuclear power and waste disposal.

**MNGN530. INTRODUCTION TO MICRO COMPUTERS IN MINING. 3.0 Semester Hrs.**

(I) General overview of the use of PC based micro computers and software applications in the mining industry. Topics include the use of: database, CAD, spreadsheets, computer graphics, data acquisition, and remote communications as applied in the mining industry. Prerequisite: Any course in computer programming. 2 hours lecture, 3 hours lab; 3 semester hours.

**MNGN536. OPERATIONS RESEARCH TECHNIQUES IN THE MINERAL INDUSTRY. 3.0 Semester Hrs.**

Analysis of exploration, mining, and metallurgy systems using statistical analysis. Monte Carlo methods, simulation, linear programming, and computer methods. Prerequisite: MNGN433. 2 hours lecture, 3 hours lab; 3 semester hours. Offered in even years.

**MNGN538. GEOSTATISTICAL ORE RESERVE ESTIMATION. 3.0 Semester Hrs.**

(I) Introduction to the application and theory of geostatistics in the mining industry. Review of elementary statistics and traditional ore reserve calculation techniques. Presentation of fundamental geostatistical concepts, including: variogram, estimation variance, block variance, kriging, geostatistical simulation. Emphasis on the practical aspects of geostatistical modeling in mining. Prerequisite: MATH323 or equivalent course in statistics; graduate or senior status. 3 hours lecture; 3 semester hours.

**MNGN539. ADVANCED MINING GEOSTATISTICS. 3.0 Semester Hrs.**

(II) Advanced study of the theory and application of geostatistics in mining engineering. Presentation of state-of-the-art geostatistical concepts, including: robust estimation, nonlinear geostatistics, disjunctive kriging, geostatistical simulation, computational aspects. This course includes presentations by many guest lecturers from the mining industry. Emphasis on the development and application of advanced geostatistical techniques to difficult problems in the mining industry today. 3 hours lecture; 3 semester hours. Offered in odd years.

**MNGN540. CLEAN COAL TECHNOLOGY. 3.0 Semester Hrs.**

(I, II) Clean Energy - Gasification of Carbonaceous Materials - including coal, oil, gas, plastics, rubber, municipal waste and other substances. This course also covers the process of feedstock preparation, gasification, cleaning systems, and the output energy blocks along with an educational segment on CO products. These output energy blocks include feedstock to electrical power, feedstock to petroleum liquids, feedstock to pipeline quality gas. The course covers co- product development including urea, fertilizers, CO2 extraction/sequestration and chemical manufacturing.

**MNGN545. ROCK SLOPE ENGINEERING. 3.0 Semester Hrs.**

Introduction to the analysis and design of slopes excavated in rock. Rock mass classification and strength determinations, geological structural parameters, properties of fracture sets, data collection techniques, hydrological factors, methods of analysis of slope stability, wedge intersections, monitoring and maintenance of final pit slopes, classification of slides. Deterministic and probabilistic approaches in slope design. Remedial measures. Laboratory and field exercise in slope design. Collection of data and specimens in the field for deterring physical properties required for slope design. Application of numerical modeling and analytical techniques to slope stability determinations for hard rock and soft rock environments. Prerequisite: none. 3 hours lecture. 3 semester hours.

**MNGN546. MINE HEALTH AND SAFETY. 2.0 Semester Hrs.**

This course focuses behaviors into a culture of safety and health consciousness is a significant management challenge, particularly in the developing world. The topics include: 1) organizational culture and behavior management, 2) strategic safety planning, 3) hazard recognition, 4) root cause analysis, 5) incident management and emergency preparedness, and 6) training programs. Learning emphasis will be balanced among fundamentals, future trends and risk depending on the specific discussion topic. The frequency of training and refresher programs throughout the project life cycle will be addressed. The importance of a health and safety culture transcending the workplace through mine employees into their families, neighbors and communities will also be discussed. This is exclusively an online course that is cohort based with limited enrollment. It is offered specifically for the Professional Masters Mining Engineering and Management Program.

**MNGN547. GEOLOGY AND MINING. 3.0 Semester Hrs.**
This course focuses on how the ore deposit geology, structure, resource assessment and geochemistry are inextricably linked to major project decisions and cost control regarding mining methods and water management. The course emphasizes fundamentals of exploration, geo-system characterization, and the risks associated with failure to integrate these aspects into decision-making. Major topics include: 1) ore genesis, 2) exploration methods, 3) geostatistics and resource development, 4) geologic hazards, 5) geochemistry and geo-environmental considerations, 6) groundwater (further addressed in Water, Waste and Closure course), and 7) geologic factors for consideration in mine design. The importance and cost efficiency of collecting and managing data concurrent with its generation will be emphasized. This is exclusively an online course that is cohort based with limited enrollment. It is offered specifically for the Professional Masters ? Mining Engineering and Management Program.

**MNGN548. INTEGRATED INFORMATION AND MINE SYSTEMS MANAGEMENT. 3.0 Semester Hrs.**
This course will focus on the role of information systems (IS) for specific mining systems in the mine life cycle. We will look at various data sources and acquisition methods like internet-of-things, crowdsourcing, and blockchain. Management of data is the principal function of an IS, so we will look at the main features and functions of a database management system (DBMS). Due to the exponential growth of unstructured data, the integration of structured data sets managed in a DBMS with big data infrastructures, which are mainly unstructured, and will be another focus of the course. Geographic Information Systems (GIS) will be introduced for managing spatial and tabular data. Advancements in sensor technologies allow the various remote sensing (RS) products to be integrated with GIS in various mining systems. The fundamental principles of design visualizations will also be explored. The IS in various full/semi-autonomous mining systems will be covered, and we will analyze the methods of interoperability and related infrastructures. We will identify cybersecurity issues related to autonomous mining systems and future trends. This is exclusively an online course that is cohort based with limited enrollment. It is offered specifically for the Professional Masters - Mining Engineering and Management Program.

**MNGN549. MARINE MINING SYSTEMS. 3.0 Semester Hrs.**
(I) Define interdisciplinary marine mining systems and operational requirements for the exploration survey, sea floor mining, hoisting, and transport. Describe and design components of deep-ocean, manganese-nodule mining systems and other marine mineral extraction methods. Analyze dynamics and remote control of the marine mining systems interactions and system components. Describe the current state-of-the-art technology, operational practice, trade-offs of the system design and risk. Prerequisite: EGGN351, EGGN320, GEOC408. 3 hours lecture; 3 semester hours. Offered alternate even years.

**MNGN550. NEW TECHNIQUES IN MINING. 3.0 Semester Hrs.**
(II) Review of various experimental mining procedures, including a critical evaluation of their potential applications. Mining methods covered include deep sea nodule mining, in situ gassification of coal, in situ retorting of oil shale, solution mining of soluble minerals, in situ leaching of metals, geothermal power generation, oil mining, nuclear fragmentation, slope caving, electro-thermal rock penetration and fragmentation. Prerequisite: Graduate standing. 3 hours lecture; 3 semester hours. Offered in even years.

**MNGN551. MINE ACCOUNTING. 2.0 Semester Hrs.**
(I, II, S) This course presents basic principles of accounting for mine engineers and managers. The preparation, content and analysis of financial statements and balance sheets from a managerial perspective are presented. Cost and accrual accounting for mine projects and operations is covered. Accounting standards in the U.S. and internationally are discussed. Mandatory financial reporting requirements for corporate entities are included in the course. 2 hours lecture; 2 semester hours.

**MNGN552. SOLUTION MINING AND PROCESSING OF ORES. 3.0 Semester Hrs.**
(II) Theory and application of advanced methods of extracting and processing of minerals, underground or in situ, to recover solutions and concentrates of value-materials, by minimization of the traditional surface processing and disposal of tailings to minimize environmental impacts. Prerequisite: Senior or graduate status. 3 hours lecture, 3 semester hours. Offered in spring.

**MNGN553. MINE DESIGN AND OPERATION PLANNING. 3.0 Semester Hrs.**
This course provides an overview of mine design and operations fundamentals with a focus on the future trends which considers where the industry will be in the next decade(s). Topics give an over-arching significance to social, environmental, health and safety considerations in traditional design and operations decision-making. Principal topics will include 1) mining methods and planning, 2) production scheduling and optimization, 3) robotics and automation, 4) equipment capabilities and selection processes, 5) mine ventilation, 6) rock mechanics and ground control, and 7) waste disposal (high level, further addressed in Water, Waste and Closure course). Project life cycle and sustainability principles will be applied throughout the course content. This is exclusively an online course that is cohort based with limited enrollment. It is offered specifically for the Professional Masters Mining Engineering and Management Program.

**MNGN554. MINE FINANCE. 2.0 Semester Hrs.**
This course describes the finance principles applicable to the mining industry. It addresses the practical application of these principles to a level of detail appropriate for a manager or executive to understand what it takes to raise money in the international marketplace sufficient to finance a corporate entity and/or a specific mining project. Topics include: 1) multi-national, national and development bank finance, 2) project and corporate finance methods (debt/equity), 3) access to capital, 4) public offerings, 5) cash and asset management, and 6) auditing. Application of finance principles throughout the project life cycle is addressed as well as regulatory aspects, financial analysis, reporting and shareholder programs. This is exclusively an online course that is cohort based with limited enrollment. It is offered specifically for the Professional Masters Mining Engineering and Management Program.

**MNGN555. MINE INVESTMENT EVALUATION. 3.0 Semester Hrs.**

This course discusses the elements, methods and analyses required to evaluate the viability and robustness of a mining project. Current practices for introducing the uncertain nature of most of the important variables in an investment analysis are addressed. While future trends and risks will be covered, course emphasis will be on the fundamentals of determining the feasibility of a project and the elements contained in a robust financial model to demonstrate that feasibility. Topics include: 1) laws and security exchange expectations for publicly disclosed documents, 2) feasibility study content, 3) responsibilities of the Qualified Person, 4) capital and operating cost estimation, 5) accruals and taxes, 6) financial analysis and cash flow modeling, 7) sensitivity analysis, and 8) public reporting. This is exclusively an online course that is cohort based with limited enrollment. It is offered specifically for the Professional Masters Mining Engineering and Management Program.

**MNGN556. MINE WATER AND ENVIRONMENT. 3.0 Semester Hrs.**

Equivalent with CEEN556,

(I) This course will cover core aspects of mine water and mining geotechnics. The main topics to be covered relate to surface and groundwater flow along open pits and underground excavations, tailings and impoundments, mine spoils and waste rock, reclamation and closure. Course emphasizes leadership, teamwork, communication, and creative problem solving skills through the use of case examples, homework, and exams which emphasize typical water and geotechnical problems relevant to the mining industry. Prerequisite: CHGN121, CHGN122. 3 hours lecture, 3 semester hours.

**MNGN557. MINERAL ECONOMICS AND POLICY. 2.0 Semester Hrs.**

This course is designed to help students learn some of the basic economic principles that will help them better understand mineral commodity market behavior and the important factors that drive mineral supply, demand, prices and other market elements. The course is designed to help you build the economic, market and policy knowledge and skills to effectively participate in a company?s decision-making and strategic management discussions. It concentrates on the economic factors and principles that mine managers and executives need to recognize, analyze and deal with in order to position their company for long-term success in volatile commodity markets. The overall objective of this course is not to make students mineral economists, but to make them a better managers and leaders by developing a practical understanding of the commodity markets in which they will deal. It will also give them a deeper knowledge of government's perspective and role in the mineral industry. This is exclusively an online course that is cohort based with limited enrollment. It is offered specifically for the Professional Masters Mining Engineering and Management Program.

**MNGN558. MINERAL PROCESSING. 3.0 Semester Hrs.**

This course addresses the fundamentals for developing an appropriate and cost-efficient mineral process for a given ore type and the risks that factor into deploying the selected process. Consideration will be given for the need to demonstrate a proven and robust process to potential investors (a ?bankable? process). Topics will include 1) unit operations and material handling, 2) sampling techniques specific to process considerations, 3) material testing and data organization and management, 4) water and energy considerations, 5) mill design and development (concept through construction), and 6) process waste disposal (high level, further addressed in Water, Waste and Closure course). Timing of process design within the project life cycle will be addressed. This is exclusively an online course that is cohort based with limited enrollment. It is offered specifically for the Professional Masters Mining Engineering and Management Program.

**MNGN559. MECHANICS OF PARTICULATE MEDIA. 3.0 Semester Hrs.**

(1) This course allows students to establish fundamental knowledge of quasi-static and dynamic particle behavior that is beneficial to interdisciplinary material handling processes in the chemical, civil, materials, metallurgy, geophysics, physics, and mining engineering. Issues of interst are the definition of particl size and size distribution, particle shape, nature of packing, quasi-static behavior under different external loading, particle collisions, kinetic theoretical modeling of particulate flows, molecular dynamic simulations, and a brief introduction of solid-fluid two-phase flows. Prerequisite: none. 3 hours lecture; 3 semester hours. Fall semesters, every other year.

**MNGN560. INDUSTRIAL MINERALS PRODUCTION. 3.0 Semester Hrs.**

(II) This course describes the engineering principles and practices associated with quarry mining operations related to the cement and aggregate industries. The course will cover resource definition, quarry planning and design, extraction, and processing of minerals for cement and aggregate production. Permitting issues and reclamation, particle sizing and environmental practices, will be studied in depth.

**MNGN561. PROJECT MANAGEMENT. 3.0 Semester Hrs.**

This course addresses the many aspects of business and project management. As the business environment changes, mine managers and executives face competing pressures to deliver both profits and effective social, environmental and economic results. Leadership is a fundamental tool for the effective executive. While a solid base of technical and operational skills is required, they must also engage a workforce, build and retain employees and seize opportunities for growth and development. While the course will address future trends and risks, emphasis will be on the fundamentals of effective business and project management. Topics include: 1) leadership, 2) project planning and controls, 3) quality assurance, 4) business process improvement, 5) risk assessment techniques, 6) personnel management and 7) conflict resolution. Because the leadership role is one that goes beyond the workplace, the course will explore the project manager?s role in communications and supporting sustainable investments. This is exclusively an online course that is cohort based with limited enrollment. It is offered specifically for the Professional Masters Mining Engineering and Management Program.

**MNGN562. MINING ENVIRONMENTAL AND SOCIAL RESPONSIBILITY. 2.0 Semester Hrs.**

This course explores the fundamentals of, and to the extent relevant, the future trends in building environmentally and socially responsible mining projects in the context of the project life cycle. Emphasis will be on 1) host country and international industry regulatory expectations and good practice; 2) communication strategies, stakeholder engagement, and building community support; 3) mining project screening and scoping, 4) characterization of environmental and social media; 5) predicting project-induced environmental and social impacts and identifying plausible mitigating actions to reduce adverse impacts to acceptable levels and enhance project benefits; and 6) developing and implementing effective social and environmental management systems. Course emphasis will be on executing these fundamentals adequately and in a culturally appropriate manner, and on the risk to project continuity and corporate reputation if these fundamentals are mishandled. This is exclusively an online course that is cohort based with limited enrollment. It is offered specifically for the Professional Masters ? Mining Engineering and Management Program.

**MNGN563. PM - WATER WASTE AND MINE CLOSURE. 3.0 Semester Hrs.**
(I, II, S) The course addresses the fundamentals and future trends in water and waste management and the design and implementation of mine closure techniques. Emphasis will be placed on the environmental, social, and cost control risks. Topics covered include: 1) water supply, disposal and treatment, 2) site-wide water management, 3) mine waste rock management, 4) process waste and tailings management, 5) solid, hazardous and medical waste disposal, 6) closure design (conceptual to construction-ready), and 7) post-closure elements. The importance of effective water and waste management practices, as well as integrating closure planning techniques into engineering designs, will be stressed throughout the project life cycle. 3 hours lecture; 3 semester hours.

**MNGN565. MINE RISK MANAGEMENT. 3.0 Semester Hrs.**
(II) Fundamentals of identifying, analyzing, assessing and treating risks associated with the feasibility, development and operation of mines. Methodologies for identifying, assessing and treating risks will be presented and practiced in case studies and exercises. Concepts and principles for analyzing risks will be demonstrated and practiced utilizing deterministic and stochastic models, deductive models, decision trees and other applicable principles. 3 hours lecture; 3 semester hours.

**MNGN567. SUSTAINABLE DEVELOPMENT AND EARTH RESOURCES. 3.0 Semester Hrs.**
(II) Earth resource industries are increasingly being called on to contribute to sustainable development in the communities and regions in which they take place. In this graduate level course, students will develop an understanding and appreciation of the ways in which resource extraction projects can contribute to sustainable development. The course will be framed around the UN Sustainable Development Goals and will include the following elements: 1) examination of sustainable development principles relevant to mining and energy projects and current best practices and continuing challenges; 2) critical assessment of necessary elements of corporate social responsibility policies and practices; 3) evaluation of stakeholder roles and specify strategies for effective stakeholder engagement; 4) identification of criteria for engineering and management that contribute to sustainable development; and 5) evaluation of real cases that demonstrate where social license to operate was either gained/maintained or not granted/withdrawn. 2 hours lecture; 3 hours lab; 3 hours total.

**MNGN570. SAFETY AND HEALTH MANAGEMENT IN THE MINING INDUSTRY. 3.0 Semester Hrs.**
(I) Fundamentals of managing occupational safety and health at a mining operation. Includes tracking of accident and injury statistics, risk management, developing a safety and health management plan, meeting MSHA regulatory requirements, training, safety audits and accident investigations. 3 hours lecture; 3 semester hours.

**MNGN571. ENERGY, NATURAL RESOURCES, AND SOCIETY. 3.0 Semester Hrs.**
(I) This is a graduate course that applies a social science lens to understanding the intersections between energy and mineral developments and communities. In this seminar-style course, we will examine these intersections through a case study approach that includes directed readings, such as ethnographies and peer-reviewed journal articles, and that incorporates student-led discussions and research projects. By exploring various development initiatives, such as oil and gas, mining, wind, solar, nuclear, and hydropower, students will gain a comprehensive understanding of the energy-mineral-society nexus and the role communities play in both furthering and limiting these developments. 3 hours lecture; 3 semester hours.

**MNGN575. HEAT MINING. 3.0 Semester Hrs.**
(I) Heat Mining focuses on identifying available sub-surface heat sources. Heat trapped in crystalline rock deep underground is available by engineering an artificial geothermal system. Hot geothermal fluid, heat generated by underground coal fire and hot water trapped in abandoned underground mine are some of other examples. We will discuss how to find them, how to estimate them, and how to extract and convert them to a usable energy form. The concept of sustainable resource development will be taught as the foundation of heat mining. Prerequisites: None. 3 hours lecture; 3 semester hours.

**MNGN585. MINING ECONOMICS. 3.0 Semester Hrs.**
(I) Advanced study in mine valuation with emphasis on revenue and cost aspects. Topics include price and contract consideration in coal, metal and other commodities; mine capital and operating cost estimation and indexing; and other topics of current interest. Prerequisite: MNGN427 or EBGN504 or equivalent. 3 hours lecture; 3 semester hours. Offered in even years.

**MNGN590. MECHANICAL EXCAVATION IN MINING. 3.0 Semester Hrs.**
(II) This course provides a comprehensive review of the existing and emerging mechanical excavation technologies for mine development and production in surface and underground mining. The major topics covered in the course include: history and development of mechanical excavators, theory and principles of mechanical rock fragmentation, design and performance of rock cutting tools, design and operational characteristics of mechanical excavators (e.g. continuous miners, roadheaders, tunnel boring machines, raise drills, shaft borers, impact miners, slotters), applications to mine development and production, performance prediction and geotechnical investigations, costs versus conventional methods, new mine designs for applying mechanical excavators, case histories, future trends and anticipated developments and novel rock fragmentation methods including water jets, lasers, microwaves, electron beams, penetrators, electrical discharge and sonic rock breakers. Prerequisite: Senior or graduate status. 3 hours lecture; 3 semester hours. Offered in odd years.

**MNGN598. SPECIAL TOPICS IN MINING ENGINEERING. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**MNGN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**MNGN625. GRADUATE MINING SEMINAR. 1.0 Semester Hr.**
(I, II) Discussions presented by graduate students, staff, and visiting lecturers on research and development topics of general interest. Required of all graduate students in mining engineering every semester during residence. 1 semester hour upon completion of thesis or residence.

**MNGN698. SPECIAL TOPICS IN MINING ENGINEERING. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**MNGN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**MNGN700. GRADUATE ENGINEERING REPORTMASTER OF ENGINEERING. 1-6 Semester Hr.**
(I, II) Laboratory, field, and library work for the Master of Engineering report under supervision of the student?s advisory committee. Required of candidates for the degree of Master of Engineering. Variable 1 to 6 hours. Repeatable for credit to a maximum of 6 hours.

**MNGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

## Interim Department Head

Jamal Rostami

## Associate Department Head

Jürgen Brune

## Professors

Corby Anderson

Kadri Dagdelen

H. Sebnem Düzgün

Linda Figueroa

Priscilla P. Nelson

M. Ugur Ozbay

Patrick R. Taylor

## Associate Professors

Hugh B. Miller

Masami Nakagawa

Jamal Rostami

## Assistant Professors

Elizabeth A. Holley

Rennie Kaunda

Nicole Smith

## Professors of Practice

Jürgen Brune

Barbara Filas

John Grubb

Robert Reeves

## Research Professor

D. Erik Spiller

## Research Assistant Professor

Richard Gilmore

## Adjunct Faculty

Matt Collins

Matt Morris

Andy Schissler

William R. Wilson

# Petroleum Engineering

## Degrees Offered

- Professional Masters in Petroleum Reservoir Systems
- Master of Engineering in Petroleum Engineering
- Master of Science in Petroleum Engineering
- Doctor of Philosophy in Petroleum Engineering
- Graduate Certificate in Petroleum Geophysics

## Program Description

The Petroleum Engineering Department offers a Professional Masters in Petroleum Reservoir Systems. This is an interdisciplinary program with geology, geophysics, and petroleum engineering components. Students will take a set curriculum of 30 hours of course work between all three disciplines. The department also offers a choice of a Master of Science (MS) degree or a Master of Engineering (ME) degree. For the MS degree, a thesis is required in addition to course work. For the ME degree, no thesis is required, but the course work requirement is greater than that for the MS degree. The Petroleum Engineering Department also offers Petroleum Engineering (PE) undergraduate students the option of a Combined Undergraduate/Graduate Program. This is an accelerated program that provides the opportunity for PE students to get a head start on their graduate education.

Applications from students having a MS in Petroleum Engineering, or in another complimentary discipline, will be considered for admission to the Doctor of Philosophy (PhD) program. To obtain the PhD degree, a student must demonstrate unusual competence, creativity, and dedication in the degree field. In addition to extensive course work, a dissertation is required for the PhD degree.

## Applying for Admission

All graduate applicants must have taken core engineering, math and science courses before applying to graduate school. For the Colorado School of Mines this would be 3 units of Calculus, 2 units of Chemistry with Quantitative Lab, 2 units of Physics, Differential Equations, Statics, Fluid Mechanics, Thermodynamics and Mechanics of Materials. To apply for admission, follow the procedure outlined in the general section of this catalog. Three letters of recommendation must accompany the application. The Petroleum Engineering Department requires the general test of the Graduate Record Examination (GRE) for applicants to all degree levels.

Applicants for the Master of Science, Master of Engineering, and Professional Masters in Petroleum Reservoir Systems programs should have a minimum score of 155 or better and applicants for the PhD program are expected to have 159 or better on the quantitative section of the GRE exam, in addition to acceptable scores in the verbal and analytical sections. The GPA of the applicant must be 3.0 or higher. The graduate application review committee determines minimum requirements accordingly, and these requirements may change depending on the application pool for the particular semester. The applicants whose native language is not English are also expected to provide satisfactory scores on the TOEFL (Test of English as a Foreign Language) exam as specified in the general section of this catalog.

## Required Curriculum

A student in the graduate program selects course work by consultation with the Faculty Advisor and with the approval of the graduate committee. Course work is tailored to the needs and interests of the student. Students who do not have a BS degree in petroleum engineering must take deficiency courses as required by the department as soon as possible in their graduate programs. Depending on the applicant's undergraduate degree, various basic undergraduate petroleum engineering and geology courses will be required. These deficiency courses are not counted towards the graduate degree; nonetheless, the student is expected to pass the required courses and the grades received in these courses are included in the GPA. Not passing these courses can jeopardize the student's continuance in the graduate program. It is desirable for students with deficiencies to complete the deficiencies or course work within the first two semesters of arrival to the program or as soon as possible with the approval of their advisor.

All PE graduate students are required to complete 3 credit hours of course work in writing, research, or presentation intensive classes, such as SYGN683, SYGN684, PEGN681 LICM501, SYGN501, and SYGN600, as agreed to by their graduate advisor.

## Fields of Research

Current fields of research include:

- Rock and fluid properties, phase behavior, and rock mechanics
- Geomechanics
- Formation evaluation, well test analysis, and reservoir characterization
- Oil recovery processes
- IOR/EOR Methods
- Naturally fractured reservoirs
- Analytical and numerical modeling of fluid flow in porous media
- Pore-scale modeling and flow in nanopores
- Development of unconventional oil and gas plays
- Geothermal energy
- Gas Hydrates
- Completion and stimulation of wells
- Horizontal and multilateral wells
- Multi-stage fracturing of horizontal wells
- Drilling management and rig automation
- Fluid flow in wellbores and artificial lift
- Drilling mechanics, directional drilling,
- Extraterrestrial drilling
- Ice coring and drilling
- Bit vibration analysis, tubular buckling and stability, wave propagation in drilling tubulars
- Laser technology in penetrating rocks
- Environment, health, and safety in oil and gas industry

Research projects may involve professors and graduate students from other disciplines. Projects may include off-campus laboratories, institutes, and other resources.

The Petroleum Engineering Department houses a research institute, two research centers, and two consortia.

## Research Institute

- Unconventional Natural Gas and Oil Institute (UNGI)

## Research Centers

- Marathon Center of Excellence for Reservoir Studies (MCERS)
- Center for Earth Mechanics, Materials, and Characterization (CEMMC)

## Research Consortia

- Fracturing, Acidizing, Stimulation Technology (FAST) Consortium.
- Unconventional Reservoir Engineering Project (UREP) Consortium.

## Special Features

In the exchange programs with the Petroleum Engineering Departments of the Mining University of Leoben, Austria, Technical University in Delft, Holland, and the University of Adelaide, Australia, a student may spend one semester abroad during graduate studies and receive full transfer of credit back to Colorado School of Mines with prior approval of the Petroleum Engineering Department at Colorado School of Mines.

Marquez Hall is home to the Petroleum Engineering Department. A prominent campus landmark, Marquez Hall showcases Mines' longstanding strengths in its core focus areas and our commitment to staying at the forefront of innovation. The building is designed using aggressive energy saving strategies and LEED certified. Marquez Hall is the first building on the Colorado School of Mines Campus that is funded entirely by donations.

The Petroleum Engineering Department enjoys strong collaboration with the Geology and Geological Engineering Department and Geophysics Department at Colorado School of Mines. Courses that integrate the faculty and interests of the three departments are taught at the undergraduate and graduate levels.

The department is close to oil and gas field operations, oil companies and laboratories, and geologic outcrops of producing formations. There are many opportunities for summer and part-time employment in the oil and gas industry.

Each summer, several graduate students assist with the field sessions designed for undergraduate students. The field sessions in the past several years have included visits to oil and gas operations in Alaska, Canada, Southern California, the Gulf Coast, the Northeast US, the Rocky Mountain regions, and western Colorado.

The Petroleum Engineering Department encourages student involvement with the Society of Petroleum Engineers, the American Association of Drilling Engineers and the American Rock Mechanics Association. The department provides some financial support for students attending the annual technical conferences for these professional societies.

## Program Requirements

## Professional Masters in Petroleum Reservoir Systems

The **Professional Masters in Petroleum Reservoir Systems (PMPRS)** degree is designed for individuals who have petroleum industry experience and are interested in increasing their knowledge across the disciplines of geology, geophysics, and petroleum engineering. This is an interdisciplinary, non-thesis master's degree for students interested in working as geoscience professionals in the petroleum industry. Details including program requirements and description can be found on the Interdisciplinary section of the catalog or by searching for the Petroleum Reservoir Systems.

## Master of Engineering

Candidates for the non-thesis **Master of Engineering** degree must complete a minimum of 30 hours of graduate course credit. At least 15 of the credit hours must be from the Petroleum Engineering Department. Up to 12 graduate credit hours can be transferred from another institution, and up to 9 credit hours of senior-level courses may be applied to the degree. All courses must be approved by the student's advisor and the department head. No graduate committee is required. No more than six credit hours can be earned through independent study.

## Master of Science

Candidates for the **Master of Science** degree must complete at least 24 graduate credit hours of course work, approved by the candidate's graduate committee, and a minimum of 6 hours of research credit. At least 12 of the course credit hours must be from the Petroleum Engineering Department. Up to 9 credit hours may be transferred from another institution. Up to 9 credit hours of senior-level courses may be applied to the degree. For the MS degree, the student must demonstrate ability to observe, analyze, and report original scientific research. For other requirements, refer to the general instructions of the Graduate School (p. 7) in this bulletin.

## Doctor of Philosophy

A candidate for the **PhD** must complete at least 48 hours of course credit and a minimum of 30 credit hours of research beyond the Bachelor's degree. A student with a Master's degree is allowed to transfer up to 24 hours of course credit from the Master's degree into the PhD program upon approval of the department and the student's thesis committee. Students may additionally transfer up to 21 graduate credit hours of course work from another institution with the approval of the graduate advisor, under the condition that these hours were not previously used for a degree or a certificate. PhD students must complete at least half of their minimally required course credit hours from the Petroleum Engineering Department and a minimum of 6 credit hours of their required course credit outside the Petroleum Engineering Department. The student's faculty advisor, thesis committee, and the department head must approve the course selection. Full-time PhD students must satisfy the following requirements for admission to candidacy within the first two calendar years after enrolling in the program:

1. Have a thesis committee appointment form on file,
2. Complete all prerequisite courses successfully,
3. Demonstrate adequate preparation for and satisfactory ability to conduct doctoral research by successfully completing a series of written and/or oral examinations and fulfilling the other requirements of their graduate committees as outlined in the department's graduate handbook.

Failure to fulfill these requirements within the time limits specified above may result in immediate mandatory dismissal from the PhD program according to the procedure outlined in the section of this Bulletin titled "General Regulations—Unsatisfactory Academic Performance—Unsatisfactory Academic Progress Resulting in Probation or Discretionary Dismissal." For other requirements, refer to the general directions of the Graduate School (p. 7) in this bulletin and/or the Department's Graduate Student Handbook.

## Combined Undergraduate/Graduate Degree Program

The requirements for the **Combined Undergraduate/Graduate Program** are defined in the section of this Bulletin titled "Graduate Degrees and Requirements—V. Combined Undergraduate/Graduate Programs." After the student is granted full graduate status, the requirements are the same as those for the non-thesis Master of Engineering or thesis-based Master of Science degree, depending to which program the student was accepted. The combined undergraduate/graduate program allows students to fulfill part of the requirements of their graduate degree by including up to 6 credit hours of their undergraduate course credits upon approval of the department. These courses must have been passed with a "B-" or better. The student must apply for the program by submitting an application through the Graduate School before the first semester of their Senior year. For other requirements, refer to the general directions of the Graduate School (p. 7) in this bulletin.

## Program Requirements

## Graduate Certificate in Petroleum Geophysics

The Graduate Certificate in Petroleum Geophysics will be a fully online certificate.  The applicant is required to have an undergraduate degree to be admitted into the program. Students working towards their Certificate are required to take 12 credits consisting of the following courses:

| | | |
|---|---|---|
| GPGN519 | ADVANCED FORMATION EVALUATION | 3.0 |
| GPGN547 | PHYSICS, MECHANICS, AND PETROPHYSICS OF ROCKS | 3.0 |
| GPGN558 | SEISMIC DATA INTERPRETATION AND QUANTITATIVE ANALYSIS | 3.0 |
| GPGN651 | ADVANCED SEISMOLOGY | 3.0 |

Students must achieve a minimum average grade of B (3.0) for the four required courses.

## Courses

**PEGN501. APPLICATIONS OF NUMERICAL METHODS TO PETROLEUM ENGINEERING. 3.0 Semester Hrs.**
The course will solve problems of interest in Petroleum Engineering through the use of spreadsheets on personal computers and structured FORTRAN programming on PCs or mainframes. Numerical techniques will include methods for numerical quadrature, differentiation, interpolation, solution of linear and nonlinear ordinary differential equations, curve fitting and direct or iterative methods for solving simultaneous equations. Prerequisites: PEGN414 and PEGN424. 3 hours lecture; 3 semester hours.

**PEGN502. ADVANCED DRILLING FLUIDS. 3.0 Semester Hrs.**
The physical properties and purpose of drilling fluids are investigated. Emphasis is placed on drilling fluid design, clay chemistry, testing, and solids control. Prerequisite: PEGN311. 2 hours lecture, 3 hours lab; 3 semester hours.

**PEGN503. INTEGRATED EXPLORATION AND DEVELOPMENT. 3.0 Semester Hrs.**
(I) Students work alone and in teams to study reservoirs from fluvial-deltaic and valley fill depositional environments. This is a multidisciplinary course that shows students how to characterize and model subsurface reservoir performance by integrating data, methods and concepts from geology, geophysics and petroleum engineering. Activities include field trips, computer modeling, written exercises and oral team presentations. Prerequisite: none. 2 hours lecture, 3 hours lab; 3 semester hours. Offered fall semester, odd years.

**PEGN504. INTEGRATED EXPLORATION AND DEVELOPMENT. 3.0 Semester Hrs.**
(I) Students work in multidisciplinary teams to study practical problems and case studies in integrated subsurface exploration and development. The course addresses emerging technologies and timely topics with a general focus on carbonate reservoirs. Activities include field trips, 3D computer modeling, written exercises and oral team presentation. Prerequisite: none. 3 hours lecture and seminar; 3 semester hours. Offered fall semester, even years.

**PEGN505. HORIZONTAL WELLS: RESERVOIR AND PRODUCTION ASPECTS. 3.0 Semester Hrs.**
This course covers the fundamental concepts of horizontal well reservoir and production engineering with special emphasis on the new developments. Each topic covered highlights the concepts that are generic to horizontal wells and draws attention to the pitfalls of applying conventional concepts to horizontal wells without critical evaluation. There is no set prerequisite for the course but basic knowledge on general reservoir engineering concepts is useful. 3 hours lecture; 3 semester hours.

**PEGN506. ENHANCED OIL RECOVERY METHODS. 3.0 Semester Hrs.**
Enhanced oil recovery (EOR) methods are reviewed from both the qualitative and quantitative standpoint. Recovery mechanisms and design procedures for the various EOR processes are discussed. In addition to lectures, problems on actual field design procedures will be covered. Field case histories will be reviewed. Prerequisite: PEGN424. 3 hours lecture; 3 semester hours.

**PEGN507. INTEGRATED FIELD PROCESSING. 3.0 Semester Hrs.**
Integrated design of production facilities covering multistage separation of oil, gas, and water, multiphase flow, oil skimmers, natural gas dehydration, compression, crude stabilization, petroleum fluid storage, and vapor recovery. Prerequisite: PEGN411. 3 hours lecture; 3 semester hours.

**PEGN508. ADVANCED ROCK PROPERTIES. 3.0 Semester Hrs.**
Application of rock mechanics and rock properties to reservoir engineering, well logging, well completion and well stimulation. Topics covered include: capillary pressure, relative permeability, velocity effects on Darcy?s Law, elastic/mechanical rock properties, subsidence, reservoir compaction, and sand control. Prerequisites: PEGN423 and PEGN426. 3 hours lecture; 3 semester hours.

**PEGN511. ADVANCED THERMODYNAMICS AND PETROLEUM FLUIDS PHASE BEHAVIOR. 3.0 Semester Hrs.**
Essentials of thermodynamics for understanding the phase behavior of petroleum fluids such as natural gas and oil. Modeling of phase behavior of single and multi-component systems with equations of states with a brief introduction to PVT laboratory studies, commercial PVT software, asphaltenes, gas hydrates, mineral deposition, and statistical thermodynamics. Prerequisites: PEGN310 and PEGN305 or equivalent. 3 hours lecture; 3 semester hours.

**PEGN512. ADVANCED GAS ENGINEERING. 3.0 Semester Hrs.**
The physical properties and phase behavior of gas and gas condensates will be discussed. Flow through tubing and pipelines as well as through porous media is covered. Reserve calculations for normally pressured, abnormally pressured and water drive reservoirs are presented. Both stabilized and isochronal deliverability testing of gas wells will be illustrated. Prerequisite: PEGN423. 3 hours lecture; 3 semester hours.

**PEGN513. RESERVOIR SIMULATION I. 3.0 Semester Hrs.**
The course provides the rudiments of reservoir simulation, which include flow equations, solution methods, and data requirement. Specifically, the course covers: equations of conservation of mass, conservation of momentum, and energy balance; numerical solution of flow in petroleum reservoirs by finite difference (FD) and control volume FD; permeability tensor and directional permeability; non-Darcy flow; convective flow and numerical dispersion; grid orientation problems; introduction to finite element and mixed finite-element methods; introduction to hybrid analytical/numerical solutions; introduction to multi-phase flow models; relative permeability, capillary pressure and wettability issues; linear equation solvers; streamline simulation; and multi-scale simulation concept. Prerequisite: PEGN424 or equivalent, strong reservoir engineering background, and basic computer programming knowledge. 3 credit hours. 3 hours of lecture per week.

**PEGN514. PETROLEUM TESTING TECHNIQUES. 3.0 Semester Hrs.**
Investigation of basic physical properties of petroleum reservoir rocks and fluids. Review of recommended practices for testing drilling fluids and oil well cements. Emphasis is placed on the accuracy and calibration of test equipment. Quality report writing is stressed. Prerequisite: Graduate status. 2 hours lecture, 1 hour lab; 3 semester hours. Required for students who do not have a BS in PE.

**PEGN515. RESERVOIR ENGINEERING PRINCIPLES. 3.0 Semester Hrs.**
Reservoir Engineering overview. Predicting hydrocarbon in place; volumetric method, deterministic and probabilistic approaches, material balance, water influx, graphical techniques. Fluid flow in porous media; continuity and diffusivity equations. Well performance; productivity index for vertical, perforated, fractured, restricted, slanted, and horizontal wells, inflow performance relationship under multiphase flow conditions. Combining material balance and well performance equations. Future reservoir performance prediction; Muskat, Tarner, Carter and Tracy methods. Fetkovich decline curves. Reservoir simulation; fundamentals and formulation, streamline simulation, integrated reservoir studies. 3 hours lecture, 3 semester hours.

**PEGN516. PRODUCTION ENGINEERING PRINCIPLES. 3.0 Semester Hrs.**
Production Engineering Overview. Course provides a broad introduction to the practice of production engineering. Covers petroleum system analysis, well stimulation (fracturing and acidizing), artificial lift (gas lift, sucker rod, ESP, and others), and surface facilities. 3 hours lecture, 3 semester hours.

**PEGN517. DRILLING ENGINEERING PRINCIPLES. 3.0 Semester Hrs.**
Drilling Engineering overview. Subjects to be covered include overall drilling organization, contracting, and reporting; basic drilling engineering principles and equipment; drilling fluids, hydraulics, and cuttings transport; drillstring design; drill bits; drilling optimization; fishing operations; well control; pore pressure and fracture gradients, casing points and design; cementing; directional drilling and horizontal drilling. 3 hours lecture, 3 semester hours.

**PEGN519. ADVANCED FORMATION EVALUATION. 3.0 Semester Hrs.**
A detailed review of wireline well logging and evaluation methods stressing the capability of the measurements to determine normal and special reservoir rock parameters related to reservoir and production problems. Computers for log processing of single and multiple wells. Utilization of well logs and geology in evaluating well performance before, during, and after production of hydrocarbons. The sensitivity of formation evaluation parameters in the volumetric determination of petroleum in reservoirs. Prerequisite: PEGN419. 3 hours lecture; 3 semester hours.

**PEGN522. ADVANCED WELL STIMULATION. 3.0 Semester Hrs.**
(I) Basic applications of rock mechanics to petroleum engineering problems. Hydraulic fracturing; acid fracturing, fracturing simulators; fracturing diagnostics; sandstone acidizing; sand control, and well bore stability. Different theories of formation failure, measurement of mechanical properties. Review of recent advances and research areas. 3 hours lecture; 3 semester hours.

**PEGN523. ADVANCED ECONOMIC ANALYSIS OF OIL AND GAS PROJECTS. 3.0 Semester Hrs.**
Determination of present value of oil properties. Determination of severance, ad valorem, windfall profit, and federal income taxes. Analysis of profitability indicators. Application of decision tree theory and Monte Carlo methods to oil and gas properties. Economic criteria for equipment selection. Prerequisite: PEGN422 or EBGN504 or ChEN504 or MNGN427 or ChEN421. 3 hours lecture; 3 semester hours.

**PEGN524. PETROLEUM ECONOMICS AND MANAGEMENT. 3.0 Semester Hrs.**
Business applications in the petroleum industry are the central focus. Topics covered are: fundamentals of accounting, oil and gas accounting, strategic planning, oil and gas taxation, oil field deals, negotiations, and the formation of secondary units. The concepts are covered by forming companies that prepare proforma financial statements, make deals, drill for oil and gas, keep accounting records, and negotiate the participation formula for a secondary unit. Prerequisite: PEGN422. 3 hours lecture; 3 semester hours.

**PEGN530. ENVIRONMENTAL LAW AND SUSTAINABILITY. 3.0 Semester Hrs.**
Equivalent with CEEN492,CEEN592,
(II) In this course students will be introduced to the fundamental legal principles that are relevant to sustainable engineering project development. General principles of United States(U.S.) environmental regulation pertaining to air quality, water quality, waste management, hazardous substances remediation, regulation of chemical manufacture and distribution, natural resources, and energy will be discussed parallel with international laws pertaining to environmental protection and human rights. In the context of engineering project design, students will explore legal, societal, and ethical risks, and risk mitigation methodologies. 3 hours lecture; 3 semester hours.

**PEGN540. PETROLEUM DATA ANALYSIS. 3.0 Semester Hrs.**
This course will take a detailed look at the opportunities, challenges and specific requirements for petroleum data analytics for the energy industry. It starts with an introduction to data analysis and visualization packages. Three projects are assigned in drilling, production, and reservoir data analysis along with data visualization techniques. The student will be required to prepare both oral and written project updates and final results. Prerequisite: PEGN438 or instructor consent.

**PEGN541. APPLIED RESERVOIR SIMULATION. 3.0 Semester Hrs.**
Concepts of reservoir simulation within the context of reservoir management will be discussed. Course participants will learn how to use available flow simulators to achieve reservoir management objectives. They will apply the concepts to an open-ended engineering design problem. Prerequisites: PEGN424. 3 hours lecture; 3 semester hours.

**PEGN542. INTEGRATED RESERVOIR CHARACTERIZATION. 3.0 Semester Hrs.**
The course introduces integrated reservoir characterization from a petroleum engineering perspective. Reservoir characterization helps quantify properties that influence flow characteristics. Students will learn to assess and integrate data sources into a comprehensive reservoir model. Prerequisites: PEGN424. 3 hours lecture; 3 semester hours.

**PEGN547. PHYSICS, MECHANICS AND PETROPHYSICS OF ROCKS. 3.0 Semester Hrs.**
(I) This course will discuss topics in rock physics, rock mechanics and petrphysics as outlined below. The class is a combination of lectures, laboratory sessions, and critical reading and discussion of papers. Topics: Stresses, strains, stiffnesses, rock physics, petrophysics: wettability: shale analysis: seismic & log expression of various formations: diagenesis: formation evaluation. 3 hours lecture; 3 semester hours.

**PEGN550. MODERN RESERVOIR SIMULATORS. 3.0 Semester Hrs.**
Students will learn to run reservoir simulation software using a variety of reservoir engineering examples. The course will focus on the capabilities and operational features of simulators. Students will learn to use pre- and post-processors, fluid property analysis software, black oil and gas reservoir models, and compositional models. 3 hours lecture; 3 semester hours.

**PEGN551. PETROLEUM DATA ANALYTICS - FUNDAMENTALS. 3.0 Semester Hrs.**
Introduction to advanced data analytics in the Digital Oilfield. Comprehensive overview of the fundamental building blocks of the digital oilfield from the convergence of operational technology (field instrumentation and control systems) with corporate information technology infrastructure. An understanding of the data foundation for a typical oil and gas exploration and production company and the challenges of Big Data to oilfield operations (volumes, variety, velocity, and data quality). Prerequisite: DSCI403, DSCI530 or MATH530 or Instructor Approval.

**PEGN552. PETROLEUM DATA ANALYTICS - APPLICATIONS. 3.0 Semester Hrs.**
A continuation of the advanced data analytics in the Digital Oilfield. This capstone course will be to apply learnings from the previous sequence of courses to drilling/completions improvement, production analysis, reservoir management optimization, and unconventional resource development. The course requires the ability of the student to be able to collect, manage, manipulate, analyze, develop insights, and report using both written and oral means those insights using good data visualizations. Prerequisite: PEGN551 or Instructor Consent.

**PEGN577. WORKOVER DESIGN AND PRACTICE. 3.0 Semester Hrs.**
Workover Engineering overview. Subjects to be covered include Workover Economics, Completion Types, Workover Design Considerations, Wellbore Cleanout (Fishing), Workover Well Control, Tubing and Workstring Design, SlicklineOperations, Coiled Tubing Operations, Packer Selection, Remedial Cementing Design and Execution, Completion Fluids, Gravel Packing, and Acidizing. 3 hours lecture, 3 semester hours.

**PEGN590. RESERVOIR GEOMECHANICS. 3.0 Semester Hrs.**
The course provides an introduction to fundamental rock mechanics concepts and aims to emphasize their role in exploration, drilling, completion and production engineering operations. Basic stress and strain concepts, pore pressure, fracture gradient and in situ stress magnitude and orientation determination and how these properties are obtained from the field measurements, mechanisms of deformation in rock, integrated wellbore stability analysis, depletion induced compaction and associated changes in rock properties and formation strength, hydraulic fracturing and fracture stability are among the topics to be covered in this rock course. Naturally fractured formation properties and how they impact the characteristics measured in the laboratory and in field are also included in the curriculum. Several industry speakers are invited as part of the lecture series to bring practical aspects of the fundamentals of geomechanics covered in the classroom. In addition, Petrel, FLAC3D and FRACMAN software practices with associated assignments are offered to integrate field data on problems including in situ stress magnitude and orientations, pore pressure and fracture gradient prediction and rock property determination using laboratory core measurements, logs, seismic, geological data. Problems are assign for students to use the field and laboratory data to obtain static and dynamic moduli, rock failure criteria, wellbore stress concentration and failure, production induced compaction/subsidence and hydraulic fracture mechanics.

**PEGN591. SHALE RESERVOIR ENGINEERING. 3.0 Semester Hrs.**
Equivalent with PEGN615,
Fundamentals of shale-reservoir engineering and special topics of production from shale reservoirs are covered. The question of what makes shale a producing reservoir is explored. An unconventional understanding of shale-reservoir characterization is emphasized and the pitfalls of conventional measurements and interpretations are discussed. Geological, geomechanical, and engineering aspects of shale reservoirs are explained. Well completions with emphasis on hydraulic fracturing and fractured horizontal wells are discussed from the viewpoint of reservoir engineering. Darcy flow, diffusive flow, and desorption in shale matrix are covered. Contributions of hydraulic and natural fractures are discussed and the stimulated reservoir volume concept is introduced. Interactions of flow between fractures and matrix are explained within the context of dual-porosity modeling. Applications of pressure-transient, rate-transient, decline-curve and transient-productivity analyses are covered. Field examples are studied. 3 hours lecture; 3 semester hours.

**PEGN592. GEOMECHANICS FOR UNCONVENTIONAL RESOURCES. 3.0 Semester Hrs.**
A wide spectrum of topics related to the challenges and solutions for the exploration, drilling, completion, production and hydraulic fracturing of unconventional resources including gas and oil shale, heavy oil sand and carbonate reservoirs, their seal formations is explored. The students acquire skills in integrating and visualizing multidiscipline data in Petrel (a short tutorial is offered) as well as assignments regarding case studies using field and core datasets. The role of integrating geomechanics data in execution of the exploration, drilling, completion, production, hydraulic fracturing and monitoring of pilots as well as commercial applications in unlocking the unconventional resources are pointed out using examples. Prerequisite: PEGN590. 3 hours lecture; 3 semester hours.

**PEGN593. ADVANCED WELL INTEGRITY. 3.0 Semester Hrs.**
Fundamentals of wellbore stability, sand production, how to keep wellbore intact is covered in this course. The stress alterations in near wellbore region and associated consequences in the form of well failures will be covered in detailed theoretically and with examples from deepwater conventional wells and onshore unconventionalwell operations. Assignments will be given to expose the students to the real field data to interpret and evaluate cases to determinepractical solutions to drilling and production related challenges. Fluid pressure and composition sensitivity of various formations will be studied. 3 hours lecture; 3 semester hours.

**PEGN594. ADVANCED DIRECTIONAL DRILLING. 3.0 Semester Hrs.**
Application of directional control and planning to drilling. Major topics covered include: Review of procedures for the drilling of directional wells. Section and horizontal view preparation. Two and three dimensional directional planning. Collision diagrams. Surveying and trajectory calculations. Surface and down hole equipment. Common rig operating procedures, and horizontal drilling techniques. Prerequisite: PEGN311 or equivalent. 3 hours lecture; 3 semester hours.

**PEGN595. DRILLING OPERATIONS. 3.0 Semester Hrs.**
Lectures, seminars, and technical problems with emphasis on well planning, rotary rig supervision, and field practices for execution of the plan. This course makes extensive use of the drilling rig simulator. Prerequisite: PEGN311. 3 hours lecture; 3 semester hours.

**PEGN596. ADVANCED WELL CONTROL. 3.0 Semester Hrs.**
Principles and procedures of pressure control are taught with the aid of a full-scale drilling simulator. Specifications and design of blowout control equipment for onshore and offshore drilling operations, gaining control of kicks, abnormal pressure detection, well planning for wells containing abnormal pressures, and kick circulation removal methods are taught. Students receive hands-on training with the simulator and its peripheral equipment. Prerequisite: PEGN311. 3 hours lecture; 3 semester hours.

**PEGN597. TUBULAR DESIGN. 3.0 Semester Hrs.**
Fundamentals of tubulars (casing, tubing, and drill pipe) design applied to drilling. Major topics covered include: Dogleg running loads. Directional hole considerations. Design criteria development. Effects of formation pressures. Stability loads after cementing. Effects of temperature, pressure, mud weights, and cement. Helical bending of tubing. Fishing loads. Micro-annulus problem. Strengths of API tubulars. Abrasive wear while rotating drill pipe. How to design for hydrogen sulfide and fatigue corrosion. Connection selection. Common rig operating procedures. Prerequisites: PEGN311 and PEGN361 or equivalent. 3 hours lecture; 3 semester hours.

**PEGN598. SPECIAL TOPICS IN PETROLEUM ENGINEERING. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**PEGN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**PEGN601. APPLIED MATHEMATICS OF FLUID FLOW IN POROUS MEDIA. 3.0 Semester Hrs.**
This course is intended to expose petroleum-engineering students to the special mathematical techniques used to solve transient flow problems in porous media. Bessel?s equation and functions, Laplace and Fourier transformations, the method of sources and sinks, Green? s functions, and boundary integral techniques are covered. Numerical evaluation of various reservoir engineering solutions, numerical Laplace transformation and inverse transformation are also discussed. 3 hours lecture; 3 semester hours.

**PEGN603. DRILLING MODELS. 3.0 Semester Hrs.**
Analytical models of physical phenomena encountered in drilling. Casing and drilling failure from bending, fatigue, doglegs, temperature, stretch; mud filtration; corrosion; wellhead loads; and buoyancy of tubular goods. Bit weight and rotary speed optimization. Prerequisites: PEGN311 and PEGN361. 3 hours lecture; 3 semester hours.

**PEGN604. INTEGRATED FLOW MODELING. 3.0 Semester Hrs.**
Students will study the formulation, development and application of a reservoir flow simulator that includes traditional fluid flow equations and a petrophysical model. The course will discuss properties of porous media within the context of reservoir modeling, and present the mathematics needed to understand and apply the simulator. Simulator applications will be interspersed throughout the course. 3 hours lecture; 3 semester hours.

**PEGN605. WELL TESTING AND EVALUATION. 3.0 Semester Hrs.**
Various well testing procedures and interpretation techniques for individual wells or groups of wells. Application of these techniques to field development, analysis of well problems, secondary recovery, and reservoir studies. Productivity, gas well testing, pressure buildup and drawdown, well interference, fractured wells, type curve matching, and shortterm testing. Prerequisite: PEGN426. 3 hours lecture; 3 semester hours.

**PEGN606. ADVANCED RESERVOIR ENGINEERING. 3.0 Semester Hrs.**
A review of depletion type, gas-cap, and volatile oil reservoirs. Lectures and supervised studies on gravity segregation, moving gas-oil front, individual well performance analysis, history matching, performance prediction, and development planning. Prerequisite: PEGN423. 3 hours lecture; 3 semester hours.

**PEGN607. PARTIAL WATER DRIVE RESERVOIRS. 3.0 Semester Hrs.**
The hydrodynamic factors which influence underground water movement, particularly with respect to petroleum reservoirs. Evaluation of oil and gas reservoirs in major water containing formations. Prerequisite: PEGN424. 3 hours lecture; 3 semester hours.

**PEGN608. MULTIPHASE FLUID FLOW IN POROUS MEDIA. 3.0 Semester Hrs.**
The factors involved in multiphase fluid flow in porous and fractured media. Physical processes and mathematical models for micro- and macroscopic movement of multiphase fluids in reservoirs. Performance evaluation of various displacement processes in the laboratory as well as in the petroleum field during the secondary and EOR/IOR operations. Prerequisite: PEGN 424, 3 hours lecture; 3 semester hours.

**PEGN614. RESERVOIR SIMULATION II. 3.0 Semester Hrs.**
The course reviews the rudiments of reservoir simulation and flow equations, solution methods, and data requirement. The course emphasizes multi-phase flow and solution techniques; teaches the difference between conventional reservoir simulation, compositional modeling and multi-porosity modeling; teaches how to construct three-phase relative permeability from water-oil and gas-oil relative permeability data set; the importance of capillary pressure measurements and wetability issues; discusses the significance of gas diffusion and interphase mass transfer. Finally, the course develops solution techniques to include time tested implicit-pressure-explicitsaturation, sequential and fully implicit methods. Prerequisite: PEGN513 or equivalent, strong reservoir engineering background, and basic computer programming knowledge. 3 credit hours. 3 hours of lecture per week.

**PEGN619. GEOMECHANICALLY AND PHYSICOCHEMICALLY COUPLED FLUID FLOW IN POROUS MEDIA. 3.0 Semester Hrs.**
The role of physic-chemisty and geomechanics on fluid flow in porous media will be included in addition to conventional fluid flow modeling and measurmeents in porous media. The conventional as well as unconventional reservoirs will be studied with the coupling of physicochemical effects and geomechanics stresses. Assignments will be given to expose the students to the real field data in interpretation and evaluation of filed cases to determine practical solutions to drilling and production related modeling challenges. 3 hours lecture; 3 semester hours.

**PEGN620. NATURALLY FRACTURED RESERVOIRS -- ENGINEERING AND RESERVOIR SIMULATION. 3.0 Semester Hrs.**
The course covers reservoir engineering, well testing, and simulation aspects of naturally fractured reservoirs. Specifics include: fracture description, connectivity and network; fracture properties; physical principles underlying reservoir engineering and modeling naturally fractured reservoirs; local and global effects of viscous, capillary, gravity and molecular diffusion flow; dual-porosity/dual-permeability models; multi-scale fracture model; dual-mesh model; streamlin model; transient testing with non-Darcy flow effects; tracer injection and breakthrough analysis; geomechanics and fractures; compositional model; coal-bed gas model; oil and gas from fractured shale; improved and enhanced oil recovery in naturally fracture reservoirs. Prerequisite: PEGN513 or equivalent, strong reservoir engineering background, and basic computer programming knowledge. 3 hours lecture; 3 semester hours.

**PEGN624. COMPOSITIONAL MODELING - APPLICATION TO ENHANCED OIL RECOVERY. 3.0 Semester Hrs.**
Efficient production of rich and volatile oils as well as enhanced oil recovery by gas injection (lean and rich natural gas, CO2, N2, air, and steam) is of great interest in the light of greater demand for hydrocarbons and the need for CO2 sequestration. This course is intended to provide technical support for engineers dealing with such issues. The course begins with a review of the primary and secondary recovery methods, and will analyze the latest worldwide enhanced oil recovery production statistics. This will be followed by presenting a simple and practical solvent flooding model to introduce the student to data preparation and code writing. Next, fundamentals of phase behavior, ternary phase diagram, and the Peng-Robinson equation of state will be presented. Finally, a detailed set of flow and thermodynamic equations for a full-fledged compositional model, using molar balance, equation of motion and the afore-mentioned equation of state, will be developed and solution strategy will be presented. Prerequisite: PEGN513 or equivalent, strong reservoir engineering background, and basic computer programming knowledge. 3 hours lecture; 3 semester hours.

**PEGN660. CARBONATE RESERVOIRS - EXPLORATION TO PRODUCTION. 3.0 Semester Hrs.**
Equivalent with GEOL660,
(II) This course will include keynote lectures and seminars on the reservoir characterization of carbonate rocks, including geologic description, petrophysics and production engineering. Course will focus on the integration of geology, rock physics, and engineering to improve reservoir performance. Application of reservoir concepts in hands-on exercises, that include a reflection seismic, well log, and core data. 3 hours lecture; 3 semester hours.

**PEGN681. PETROLEUM ENGINEERING SEMINAR. 3.0 Semester Hrs.**
Comprehensive reviews of current petroleum engineering literature, ethics, and selected topics as related to research and professionalism. 3 hours seminar; 3 semester hour.

**PEGN698. SPECIAL TOPICS IN PETROLEUM ENGINEERING. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**PEGN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**PEGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

**SYGN683. ORAL COMMUNICATION SKILLS. 1.0 Semester Hr.**
This course is designed for ME, MS and PhD students and focuses on designing and delivering technical presentations. Course assignments will be based on technical and non-technical material relating to earth, energy, and the environment and will include the topics of professionalism, ethics and diversity. Students will work individually and in multicultural teams on assignments. There are no prerequisites for this course, however, proficiency with the English language, both oral and written, is expected prior to enrollment.

**SYGN684. WRITING SKILLS. 2.0 Semester Hrs.**
This course is designed for MS and PhD students and will focus on the research process and the technical writing process. Course assignments will be based on technical and non-technical material relating to earth, energy, and the environment and will include the topics of professionalism, ethics and diversity. Students will work individually and in multicultural teams on assignments. There are no prerequisites for PEGN684, however, proficiency with the English language, both oral and written, is expected prior to enrollment.

## Professors

Hossein Kazemi, Chesebro' Distinguished Chair

Erdal Ozkan

Yu-Shu Wu, Energi Simulation Chair

## Associate Professors

Alfred W. Eustes III

Jennifer L. Miskimins, Interim Department Head, F.H. "Mick" Merelli/ Cimarex Energy Distinguished Department Head Chair in Petroleum Engineering

Jorge H. B. Sampaio Jr.

Xiaolong Yin, Associate Department Head

Luis E. Zerpa

## Assistant Professors

Yilan Fan

## Teaching Professor

Linda A. Battalora

## Teaching Associate Professors

Mansur Ermila

Mark G. Miller

## Teaching Assistant Professor

Elio S. Dean

## Research Associate Professor

Philip H. Winterfeld

## Professor of Practice

Jim Crompton

## Adjunct Professor

William W. Fleckenstein

Trent Green

## Professor Emeritus

Ramona M. Graves, Professor and Dean Emeritus

Bill Scoggins, President Emeritus

Craig W. Van Kirk, Professor Emeritus

## Associate Professor Emeritus

Richard Christiansen, Associate Professor Emeritus

# Physics

## Degrees Offered

- Master of Science (Applied Physics)
- Doctor of Philosophy (Physics)

## Program Description

The Physics Department at Mines offers a full program of instruction and research leading to the MS in Applied Physics or PhD in Physics and is part of interdisciplinary programs in Materials Science and in Nuclear Engineering, through which students can obtain both the MS and the PhD degrees. The research in these graduate programs is supported by external grants and contracts totaling $6M/year. Research in the Department is organized under three primary themes: subatomic physics, condensed matter physics, and applied optics. With 23 faculty, 66 graduate students, and 225 undergraduate physics majors, the Physics Department at Mines is a vibrant intellectual community providing high-quality education in state-of-the-art facilities.

Graduate students are given a solid background in the fundamentals of classical and modern physics at an advanced level and are encouraged early in their studies to learn about the research interests of the faculty so that a thesis topic can be identified.

## Program Requirements

Students entering graduate programs in the Physics Department will select an initial program in consultation with the departmental graduate student advising committee until such time as a research field has been chosen and a thesis committee appointed.

## Master of Science

Requirements: 20 semester hours of course work in an approved program, plus 16 semester hours of research credit, with a satisfactory thesis.

## Mines’ Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines’ combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any 400+ level courses that count towards the undergraduate degree requirements as "Elective Coursework" or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a "B-" or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

## Doctor of Philosophy

Requirements: 32 semester hours of course work in an approved program, plus 40 semester hours of research credit, with a satisfactory thesis. 12 semester hours of course work will be in a specialty topic area defined in consultation with the thesis advisor. Possible specialty topic areas within the Physics Department exist in Optical Science and Engineering, Condensed Matter Physics, Theoretical Physics, Renewable Energy Physics, and Nuclear/Particle Physics and Astrophysics.

To demonstrate adequate preparation for the PhD degree in Physics, each student must achieve a grade of 3.0 or better in each core course. Students not meeting this standard must pass oral examinations covering the relevant core courses or retake the courses with a grade of 3.0 or better within one year. This process is part of the requirement for admission to candidacy, which full time PhD students must complete within two calendar years of admission, as described in the campus-wide graduate degree requirements (p. 37) section of this bulletin. Other degree requirements, time limits, and procedural details can be found in the Physics Department Graduate Student Advising Brochure.

## Physics Colloquium

All full-time physics graduate students must attend the Physics Colloquium, which is represented in the curriculum by the Graduate Seminar courses. Students must take one of these courses every semester that they are enrolled at CSM. Those students who are in the MS Program, sign up for PHGN501 (fall) and PHGN502 (spring). Students in the PhD program sign up for PHGN601 (fall) and PHGN602 (spring). At the end of each semester students are assigned either a satisfactory or unsatisfactory progress grade, based on attendance, until the final semester of the student's degree program, when a letter grade is assigned based on all prior semesters' attendance grades. As a result, while these courses are taken each year, only 1 hour total of course credit is conferred for each of 501, 502, 601, or 602. Students who have official part-time status and who have already taken at least one semester of 501 and 502 for the MS degree, or 601 and 602 for the PhD degree are not required to sign up for Graduate Seminar during subsequent semesters.

## Prerequisites

The Graduate School of the Colorado School of Mines is open to graduates from four-year programs at accredited colleges or universities. Admission to the Physics Department MS and PhD programs is competitive and is based on an evaluation of undergraduate performance, standardized test scores, and references. The undergraduate course of study of each applicant is evaluated according to the requirements of the Physics Department.

## Required Curriculum

## Master of Science in Applied Physics

| Core Courses | | |
|---|---|---|
| PHGN511 | MATHEMATICAL PHYSICS | 3.0 |
| PHGN520 | QUANTUM MECHANICS I | 3.0 |
| | Select one of the following: | 3.0 |
| PHGN505 | CLASSICAL MECHANICS I | |
| PHGN507 | ELECTROMAGNETIC THEORY I | |
| PHGN521 | QUANTUM MECHANICS II | |
| PHGN530 | STATISTICAL MECHANICS | |
| PH ELECT | Electives | 9.0 |
| PHGN501 & PHGN502 | GRADUATE SEMINAR and GRADUATE SEMINAR * | 2.0 |
| PHGN707 | Master's Thesis | 16.0 |
| Total Semester Hrs | | 36.0 |

* Graduate Seminar: Each full-time MS graduate student will register for Graduate Seminar each semester for a total of 2 semester hours of credit cumulative over the degree.

## Doctor of Philosophy in Physics

| Core Courses | | |
|---|---|---|
| PHGN505 | CLASSICAL MECHANICS I | 3.0 |
| PHGN507 | ELECTROMAGNETIC THEORY I | 3.0 |
| PHGN511 | MATHEMATICAL PHYSICS | 3.0 |
| PHGN520 | QUANTUM MECHANICS I | 3.0 |
| PHGN521 | QUANTUM MECHANICS II | 3.0 |
| PHGN530 | STATISTICAL MECHANICS | 3.0 |
| PHGN601<br>& PHGN602 | ADVANCED GRADUATE SEMINAR<br>and ADVANCED GRADUATE SEMINAR * | 2.0 |
| PH ELECT | Special topic area electives | 12.0 |
| PHGN707 | Doctoral Thesis | 40.0 |
| Total Semester Hrs | | 72.0 |

* Graduate Seminar: Each full-time PhD graduate student will register for Graduate Seminar each semester for a total of 2 semester hours of cumulative credit over the degree.

## Fields of Research

**Applied Optics and Biophysics:** lasers, ultrafast optics, non-linear optics, laser-produced plasmas, micromachining, multiphoton microscopy, single-molecule microscopy, total internal reflection microscopy, biophysical mechanisms of collagen fibril degradation, novel imaging techniques.

**Subatomic:** low energy nuclear structure and astrophysics, applied nuclear physics, high-energy cosmic-ray and neutrino physics, neutrinoless double beta decay,

**Condensed Matter and Materials Physics:** photovoltaics, thermoelectrics, plasmonics, materials discovery, thin-film semiconductors, amorphous materials, excitonic materials, optoelectronic materials, nanostructures and quantum dots, self-assembled systems, organic and soft condensed matter, x-ray diffraction, Raman spectroscopy, x-ray photoelectron spectroscopy, Auger spectroscopy, scanning probe microscopies, atom probe tomography, first principles condensed materials theory**,** electronic structure, topological disorder.

**Quantum Physics:** quantum chaos, strongly-correlated states, quantum computing, quantum information, quantum simulation, quantum many body theory, quantum error correction, disorder in quantum materials, applied superconductivity, low-temperature physics, spintronics.

## Courses

**PHGN501. GRADUATE SEMINAR. 1.0 Semester Hr.**
(I) M.S. students will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. See additional course registration instructions under Program Requirements above. 1 hour seminar; 1 semester hour.

**PHGN502. GRADUATE SEMINAR. 1.0 Semester Hr.**
(II) M.S. students will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. See additional course registration instructions under Program Requirements above. 1 hour seminar; 1 semester hour.

**PHGN503. RESPONSIBLE CONDUCT OF RESEARCH. 1.0 Semester Hr.**
(II) This course introduces students to the various components of responsible research practices. Subjects covered move from issues related to professional rights and obligations through those related to collaboration, communication and the management of grants, to issues dealing with intellectual property. The course culminates with students writing an ethics essay based on a series of topics proposed by the course instructor. 1 hour lecture; 1 semester hour.

**PHGN504. RADIATION DETECTION AND MEASUREMENT. 3.0 Semester Hrs.**
Physical principles and methodology of the instrumentation used in the detection and measurement of ionizing radiation. Prerequisite: none. 3 hours lecture; 3 semester hours.

**PHGN505. CLASSICAL MECHANICS I. 3.0 Semester Hrs.**
(I) Review of Lagrangian and Hamiltonian formulations in the dynamics of particles and rigid bodies; kinetic theory; coupled oscillations and continuum mechanics; fluid mechanics. Prerequisite: PHGN350 or equivalent. 3 hours lecture; 3 semester hours.

**PHGN507. ELECTROMAGNETIC THEORY I. 3.0 Semester Hrs.**
(II) To provide a strong background in electromagnetic theory. Electrostatics, magnetostatics, dynamical Maxwell equations, wave phenomena. Prerequisite: PHGN462 or equivalent and PHGN511. 3 hours lecture; 3 semester hours.

**PHGN511. MATHEMATICAL PHYSICS. 3.0 Semester Hrs.**
(I) Review of complex variable and finite and infinite-dimensional linear vector spaces. Sturm-Liouville problem, integral equations, computer algebra. Prerequisite: PHGN311 or equivalent. 3 hours lecture; 3 semester hours.

**PHGN519. FUNDAMENTALS OF QUANTUM INFORMATION. 3.0 Semester Hrs.**
This course serves as a broad introduction to quantum information science, open to students from many backgrounds. The basic structure of quantum mechanics (Hilbert spaces, operators, wavefunctions, entanglement, superposition, time evolution) is presented, as well as a number of important topics relevant to current quantum hardware (including oscillating fields, quantum noise, and more). Finally, we will survey the gate model of quantum computing, and study the critical subroutines which provide the promise of a quantum speedup in future quantum computers. Prerequisite: MATH332 (linear algebra) or an equivalent linear algebra course.

**PHGN520. QUANTUM MECHANICS I. 3.0 Semester Hrs.**
(II) Schroedinger equation, uncertainty, change of representation, one-dimensonal problems, axioms for state vectors and operators, matrix mechanics, uncertainty relations, time-independent perturbation theory, time-dependent perturbations, harmonic oscillator, angular momentum; semiclassical methods, variational methods, two-level system, sudden and adiabatic changes, applications. Prerequisite: PHGN511 and PHGN320 or equivalent. 3 hours lecture; 3 semester hours.

**PHGN521. QUANTUM MECHANICS II. 3.0 Semester Hrs.**
(I) Review of angular momentum, central potentials and applications. Spin; rotations in quantum mechanics. Formal scattering theory, Born series, partial wave analysis. Addition of angular momenta, Wigner-Eckart theorem, selection rules, identical particles. Prerequisite: PHGN520. 3 hours lecture; 3 semester hours.

**PHGN530. STATISTICAL MECHANICS. 3.0 Semester Hrs.**
(I) Review of thermodynamics; equilibrium and stability; statistical operator and ensemblesl ideal systems; phase transitions; non-equilibrium systems. Prerequisite: PHGN341 or equivalent and PHGN520. Co-requisite: PHGN521. 3 hours lecture; 3 semester hours.

**PHGN532. LOW TEMPERATURE MICROWAVE MEASUREMENTS FOR QUANTUM ENGINEERING. 3.0 Semester Hrs.**
The goal of the course is to provide hands on training in high-frequency, low-temperature measurements which are requisite for quantum information applications. This course introduces the fundamentals of high-frequency measurements, the latest techniques for accuracy-enhanced automated microwave measurements, low-temperature measurement techniques, low noise measurements, and common devices used in quantum information. The course will have three modules. The first module, basics of electronic measurements, will include chip layout, power measurements, ground loop testing, impedance measurements, noise fundamentals, cable and device fabrication and care. The second module, high frequency measurements, will include measurements of basic scattering parameters, accuracy enhancement and calibration, transmission line, amplifier, and oscillator characterization including noise measurements. The third module, low-temperature measurements, will cover critical parameters for superconductors and Josephson junctions, measurements of superconducting resonators, characterization of low-temperature electronic elements including amplifiers. At the end of this course the students will know how to use network analyzers, spectrum analyzers, cryostats, the software Eagle for chip design, amplifiers, and filters. Prerequisite: EENG385, PHGN215, or equivalent Electronics Devices & Circuits course.

**PHGN535. INTERDISCIPLINARY SILICON PROCESSING LABORATORY. 3.0 Semester Hrs.**
Equivalent with
CBEN435,CBEN535,CHEN435,CHEN535,MLGN535,PHGN435,
(II) Explores the application of science and engineering principles to the fabrication and testing of microelectronic devices with emphasis on specific unit operations and interrelation among processing steps. Teams work together to fabricate, test, and optimize simple devices. Prerequisite: none. 1 hour lecture, 4 hours lab; 3 semester hours.

**PHGN542. SOLID STATE DEVICES AND PHOTOVOLTAIC APPLICATIONS. 3.0 Semester Hrs.**
(II) An overview of the physical principles involved in the characterization, and operation of solid state devices. Topics will include: semiconductor physics, electronic transport, recombination and generation, intrinsic and extrinsic semiconductors, electrical contacts, p-n junction devices (e.g., LEDs, solar cells, lasers, particle detectors); other semiconductor devices (e.g., bipolar junction transistors and field effect transistors and capacitors). There will be emphasis on optical interactions and application to photovoltaic devices. Prerequisite: PHGN440 or equivalent. 3 hours lecture; 3 semester hours.

**PHGN545. QUANTUM MANY-BODY PHYSICS. 3.0 Semester Hrs.**
This course offers an introduction to quantum many-body physics in a modern approach from the perspectives of quantum information science. Starting from the difference between classical and quantum correlations, this course introduces composite quantum systems and the concept of entanglement as the central theme in quantum many-body physics. A system of many spin-1/2s is then presented as the paradigmatic quantum many-body system, opening the realm of quantum phase transitions and quantum simulation experiments. Next, systems of non-interacting bosons or fermions are examined using the powerful canonical transformation. To understand what happens when particles interact, the well-known Hubbard model is brought in, together with its importance in quantum materials. Finally, topological ordered quantum matter is introduced and explained via the structure of quantum entanglement. The application of topological order to quantum computing will also be mentioned.

**PHGN550. NANOSCALE PHYSICS AND TECHNOLOGY. 3.0 Semester Hrs.**
An introduction to the basic physics concepts involved in nanoscale phenomena, processing methods resulting in engineered nanostructures, and the design and operation of novel structures and devices which take advantage of nanoscale effects. Students will become familiar with interdisciplinary aspects of nanotechnology, as well as with current nanoscience developments described in the literature. Prerequisites: PHGN320, PHGN341, co-requisite: PHGN462. 3 hours lecture; 3 semester hours.

**PHGN566. MODERN OPTICAL ENGINEERING. 3.0 Semester Hrs.**
Provides students with a comprehensive working knowledge of optical system design that is sufficient to address optical problems found in their respective disciplines. Topics include paraxial optics, imaging, aberration analysis, use of commercial ray tracing and optimazation, diffraction, linear systems and optical transfer functions, detectors, and optical system examples. Prerequisite: PHGN462. 3 hours lecture; 3 semester hours.

**PHGN570. FOURIER AND PHYSICAL OPTICS. 3.0 Semester Hrs.**
This course addresses the propagation of light through optical systems. Diffraction theory is developed to show how 2D Fourier transforms and linear systems theory can be applied to imaging systems. Analytic and numerical Fourier and microscopes, spectrometers and holographic imaging. They are also applied to temporal propagation in ultrafast optics. Prerequisite: PHGN462 or equivalent. 3 hours lecture; 3 semester hours.

**PHGN585. NONLINEAR OPTICS. 3.0 Semester Hrs.**
An exploration of the nonlinear response of a medium (semiclassical and quantum descriptions) and nonlinear wave mixing and propagation. Analytic and numeric techniques to treat nonlinear dynamics are developed. Applications to devices and modern research areas are discussed, including harmonic and parametric wave modulation, phase conjugation, electro-optic modulation. Prerequiste: PHGN462 or equivalent, PHGN520. 3 hours lecture; 3 semester hours.

**PHGN590. NUCLEAR REACTOR PHYSICS. 3.0 Semester Hrs.**
Bridges the gap between courses in fundamental nuclear physics and the practice of electrical power production using nuclear reactors. Review of nuclear constituents, forces, structure, energetics, decay and reactions; interaction of radiation with matter, detection of radiation; nuclear cross sections, neutron induced reactions including scattering, absorption, and fission; neutron diffusion, multiplication, criticality; simple reactor geometries and compositions; nuclear reactor kinetics and control; modeling and simulation of reactors. Prerequisite: PHGN422.

**PHGN598. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**PHGN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**PHGN601. ADVANCED GRADUATE SEMINAR. 1.0 Semester Hr.**
(I) Ph.D. students will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. See additional course registration instructions under Program Requirements above. 1 hour seminar; 1 semester hour.

**PHGN602. ADVANCED GRADUATE SEMINAR. 1.0 Semester Hr.**
(II) Ph.D. students will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. See additional course registration instructions under Program Requirements above. 1 hour seminar; 1 semester hour.

**PHGN608. ELECTROMAGNETIC THEORY II. 3.0 Semester Hrs.**
Spherical, cylindrical, and guided waves; relativistic 4-dimensional formulation of electromagnetic theory. Prerequisite: PHGN507. 3 hours lecture; 3 semester hours. Offered on demand.

**PHGN612. MATHEMATICAL PHYSICS II. 3.0 Semester Hrs.**
Continuation of PHGN511. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered on demand.

**PHGN623. NUCLEAR STRUCTURE AND REACTIONS. 3.0 Semester Hrs.**
The fundamental physics principles and quantum mechanical models and methods underlying nuclear structure, transitions, and scattering reactions. Prerequisite: PHGN521. 3 hours lecture; 3 semester hours. Offered on demand.

**PHGN624. NUCLEAR ASTROPHYSICS. 3.0 Semester Hrs.**
The physical principles and research methods used to understand nucleosynthesis and energy generation in the universe. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered on demand.

**PHGN641. ADVANCED CONDENSED MATTER PHYSICS. 3.0 Semester Hrs.**
Provides working graduate-level knowledge of applications of solid state physics and important models to crystalline and non-crystalline systems in two and three dimensions. Review of transport by Bloch electrons; computation, interpretation of band structures. Interacting electron gas and overview of density functional theory. Quantum theory of optical properties of condensed systems; Kramers-Kronig analysis, sum rules, spectroscopies. Response and correlation functions. Theoretical models for metal-insulator and localization transitions in 1, 2, 3 dimensions (e.g., Mott, Hubbard, Anderson, Peierls distortion). Boltzmann equation. Introduction to magnetism; spin waves. Phenomenology of soft condensed matter: order parameters, free energies. Conventional superconductivity. Prerequisites: PHGN440 or equivalent, PHGN520, PHGN530. 3 hours lecture; 3 semester hours.

**PHGN698. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**PHGN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**PHGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

## Professors

Lincoln D. Carr

Charles G. Durfee III

Uwe Greife, Department Head

Mark T. Lusk

Frederic Sarazin

Jeff A. Squier

Lawrence R. Wiencke

## Associate Professors

Eliot Kapit

Timothy R. Ohno

Eric S. Toberer

## Assistant Professors

Daniel Adams

Serena M. Eley

Zhexuan Gong

Kyle G. Leach

Susanta K. Sarkar

Meenakshi Singh

Jeramy D. Zimmerman

## Teaching Professors

Kristine E. Callan

Alex T. Flournoy

Patrick B. Kohl

H. Vincent Kuo

Todd G. Ruskell

Charles A. Stone

## Teaching Assistant Professor

Emily M. Smith

## Research Professor

Reuben T. Collins

## Research Associate Professor

Wendy Adams Spencer

## Research Assistant Professors

P. David Flammer

Laith Haddad

Lakshmi Krishna

Lokender Kumar

Nitin Kumar

Gavriil Shchedrin

K. Xerxes Steirer

## Professors Emeriti

F. Edward Cecil

Thomas E. Furtak

Frank V. Kowalski

John Scales

P. Craig Taylor

John Trefny, President Emeritus

Don L. Williamson

## Associate Professors Emeriti

David M. Wood

# Interdisciplinary Programs

# Advanced Energy Systems

## Degrees Offered

- Master of Science in Advanced Energy Systems (Non-Thesis)
- Doctor of Philosophy in Advanced Energy Systems

## Program Description

The Advanced Energy Systems graduate program will leverage significant interdisciplinary technical, techno-economic and policy strengths with basic and applied research at Mines and NREL to create a unique educational and research experience. It will integrate the research strengths of both institutions to develop solutions to global challenges. Mines has a rich tradition of seeking responsible solutions to using earth resources (especially minerals and water) from survey to extraction to use and re-use, and NREL pushes the state of the art in advanced energy technologies.

With a focus on emerging energy technologies, the program is designed to empower researchers at both institutions to tackle a variety of compelling needs, including:

• Integrating a wide range of energy sources into a flexible grid as power derived from renewables approach cost parity

• Implementing digitized and optimized energy control and management through artificial intelligence that maintains robust cybersecurity

• Addressing economic and policy barriers to deployment of new clean and high-efficiency technologies for energy conversion and storage.

All enrolled students will be part of a community of students, faculty, and NREL technical staff which will foster professional development, cross-disciplinary thinking, and systems understanding of grand energy challenges. A unique aspect of the program, pertaining to the enrolled doctoral students are two, 4-month rotations at NREL to gain insight into technology research and quantitative analysis in advanced energy systems. These rotations will be integrated with professional development toward developing skills for energy research and technical leadership careers. Graduates of this degree program will be uniquely positioned to enter the workforce in roles supporting advanced energy innovation and energy systems integration in government, academia, nonprofits, and the private sector.

## Degree Requirements

The Advanced Energy Systems graduate program will offer the following two degrees:

- a 30-credit Master of Science Non-Thesis (MS-NT) degree in Advanced Energy Systems targeted for students interested in professional careers in industry, government, or non-governmental organizations;
- a PhD program in Advanced Energy Systems requiring 36 credit hours of coursework, 36 credit hours of research, and the standard on-campus residency requirement.

Both degree programs will require the three new core courses that support the program as described below. Because of the multidisciplinary nature of Advanced Energy Systems, there will be significant demands for flexibility in the Program’s curriculum beyond those three core courses. Program faculty will serve as advisors to students based on each student ‘s interests and research focus. The flexibility of the program will allow for students to pursue energy topics across the existing breadth of energy-related course offerings in the Mines graduate curriculum. It is expected that the Advanced Energy Systems degree program will encourage new energy-systems courses in an array of disciplines as the PhD and MS enrollment grows.

Students will apply to enter these Advanced Energy Systems program through Mines' Graduate School. After passing their qualifying exam (Research Performance Evaluation), PhD students will be under the discretion of the Mines' faculty research advisor and co-advising NREL staff. The Faculty Executive Committee will formally approve elective courses and monitor each student’s progress.

The Master of Science, Non-Thesis (MS-NT) is a stand-alone degree wherein students are self-supported or supported by industry or other outside sources. The MS and PhD curricula have overlap where new students in both programs will enroll in the three core program courses as part of their degree program. These core courses will be required for all MS-NT students as part of their degree and for all PhD students who enter the program without appropriate courses that can serve as transfer credits for the core courses.

## MS Non-Thesis Degree Program Requirements

The Master of Science degree program will be exclusively non-thesis and the MS students will not participate in the rotation courses (NREL Rotation: Analysis and Technology) at NREL. The MS degree program, coursework, will require 30 credit hours of coursework and start with the three core classes, worth nine credit hours. The additional 21 credit hours can be any graduate level course at Mines as long as the courses form a coherent focus for an in-depth energy study and are approved by the advisor and the Faculty Executive Committee. The intention is to allow for a wide range of specializations and needs required by the energy sector. Assigned program faculty advisors will assist MS students in course selection and approval. Faculty advisors will be selected by the Executive Committee at the beginning of each MS students’ program. MS students may apply for the PhD program and will not be required to retake the three core courses listed below.

## Mines’ Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines’ combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any 400+ level courses that count towards the undergraduate degree requirements as "Elective Coursework" or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a "B-" or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

Framework of the 9-credit core courses required for the MS-NT and PhD curricula.

| | | |
|---|---|---|
| ENGY501 | ENERGY RESOURCES AND ELECTRIC POWER SYSTEMS | 3.0 |
| ENGY502 | ENERGY FOR TRANSPORTATION | 3.0 |

| | | |
|---|---|---|
| ENGY503 | ENERGY SYSTEMS INTEGRATION AND EFFICIENCY | 3.0 |

## PhD Degree Program Requirements

The PhD degree program requires 72 total credit hours, consisting of at least 36 credit hours of coursework beyond the B.S. and at least 36 research credit hours. PhD coursework beyond the MS degree program will not be restricted other than approved by the student's advisor and dissertation committee. Students who enter the PhD program with an MS degree in a relevant engineering or science field will be expected to take at least the 9 credit hours of the core classes listed in Table 1 and the NREL-Research rotation as described below.

PhD students will be required to participate in two rotations at NREL which each count as will a 3 credit courses. The rotation courses are listed in Table 2. The 1st rotation would be carried out in the 2nd (Spring semester) and the 2nd during summer. These credits will count as research credits. Both rotations will be coupled with professional development on best research practices, networking, writing of journal articles, and preparing impactful research presentations. Assessment will be based on the work carried out, a 10-page written report, and a group presentation at end of the rotation.

Framework of 6-credit requirement for PhD students gained via rotations at NREL.

| | | |
|---|---|---|
| ENGY691 | NREL ROTATION: ANALYSIS OF INTEGRATED ENERGY SYSTEMS | 3.0 |
| ENGY692 | NREL ROTATION: ENERGY SCIENCE & TECHNOLOGIES | 3.0 |

In accordance with other PhD. programs at Mines, students in the Advanced Energy Systems PhD degree program must successfully complete qualifying examinations, defined as a research performance evaluation. This will consist of an oral defense and 10-page document based on a Research Hypothesis. PhD students who do not successfully pass the qualifying exam will be allowed to finish and MS-NT program without program financial support in subsequent semesters.

In addition to this, a minimum GPA of B+ in courses/rotations will be required to pursue doctoral studies. After completion of their course work with a satisfactory GPA, students will be required to present a dissertation research proposal to their thesis committee, which involves presenting a compelling research plan for completing the degree. Successful completion of a committee-approved plan will allow the student to be admitted to candidacy for completing the PhD program.

PhD research is aimed at fundamentally advancing the state of art in analysis and development of Advanced Energy Systems. PhD students are expected to submit the dissertation work for at least two archival publications in scholarly journals and present research findings in at least one professional conference. Students are also required to participate in the Advanced Energy Systems seminar series both by attending seminars of distinguished speakers and by presenting their research on no less than an annual basis.

Doctoral students in the Advanced Energy Systems program will be advised by a faculty advisor affiliated with the program and by an interdisciplinary Doctoral Dissertation committee, which will include two additional faculty from Mines and an affiliated researcher from NREL. The committee, together with the student, will also approve the course plan including elective courses to be taken to complete the 36 credit hour course requirement. The PhD degree program culminates in a research dissertation that significant scholarly contribution to Advanced Energy Systems as a field. Full-time enrollment is strongly encouraged and in accordance with all other graduate programs at Mines, the PhD program will have a two-semester minimum residency requirement as described in the general section of the Graduate Bulletin.

## Courses

**ENGY501. ENERGY RESOURCES AND ELECTRIC POWER SYSTEMS. 3.0 Semester Hrs.**

(I) This course will provide successful students a quantitative understanding of how fossil, renewable and nuclear energy resources are harnessed to electric power. A foundational underpinning will be the thermodynamics of energy conversion, using fundamental principles and language bridging physics, chemistry and engineering. Examples will be taken from both established and emerging technologies spanning solar, nuclear, wind fossil fuel and bioenergy conversion. Students will also learn how to analyze electricity generation, transmission, and grid-scale storage systems with a focus on the U.S. as a framework for analyzing other developing markets. 3 hours lecture; 3 semester hours.

**ENGY502. ENERGY FOR TRANSPORTATION. 3.0 Semester Hrs.**

(I) This course focuses on multiple aspects of current and proposed transportation technologies to analyze the challenges and opportunities of moving toward more sustainable transportation infrastructure. This course is designed to train students to develop analytical skills and to use computational tools for evaluating performance and environmental impacts of various vehicle and fueling technologies. Successful students will develop a basis for assessing energy resource requirements and environmental concerns within the context of technical performance, policy frameworks, and social perspectives. The course will include the following topics: travel demand and travel modes; transportation technologies; fossil-fuel and electric power plants and associated fuels; emissions ($CO2$ and pollutants) formation and impacts on air quality, climate, and human health; national/international transportation policy; and transportation planning. 3 hours lecture; 3 semester hours.

**ENGY503. ENERGY SYSTEMS INTEGRATION AND EFFICIENCY. 3.0 Semester Hrs.**

(II) This course will provide students with basic skills to analyze the operation and evolution of the electric grid and electricity utilization with a particular emphasis on trends toward increased renewable energy penetration. The course will develop students' analytical skills to evaluate how electricity generation, transmission, distribution and storage are managed and controlled. Successful students will gain a basic understanding of electromechanical machines for power conversion and AC power distribution as well as renewable energy sources and battery systems with DC storage. The course will introduce students to how efficient energy utilization and demand response management impact the electric grid performance and electricity markets. An emphasis on managing energy loads in buildings, the commercial sector, and energy-intensive manufacturing will expose students to system-level modeling tools that can assess how to manage power demands with transient power generation and market forces. The course will also address the integrated nature of energy systems with an emphases on connections to water demands and on risks arising due to cybersecurity and resiliency threats facing the electric grid. 3 hours lecture; 3 semester hours.

**ENGY691. NREL ROTATION: ANALYSIS OF INTEGRATED ENERGY SYSTEMS. 3.0 Semester Hrs.**

(I) This course introduces graduate students enrolled in the Advanced Energy Systems Program to research opportunities, culture, and expectations in energy science and technology with a particular emphasis on systems and/or policy analysis. Students will work within directorates at NREL with an emphasis on systems modeling, analysis, and/or integration. This class will engage students in a semester-long research project in energy system analysis and prepare students for best practices with respect to research project and data management, literature reading, report writing, and presentation. 1 hour lecture; 6 hours lab; 3 semester hours.

**ENGY692. NREL ROTATION: ENERGY SCIENCE & TECHNOLOGIES. 3.0 Semester Hrs.**

(I) This course prepares graduate students enrolled in the Advanced Energy Systems Program in research practices, culture, and expectations in energy science and technology with a particular emphasis on science and engineering related to energy materials, processes, and/or systems. Students will work within directorates at NREL with an emphasis on science and/or technology. This class will engage students in a semester-long research project in energy science and/or technology. Students will also learn and practice journal publication and research poster best practices, research career path planning, and proposal funding strategies. 1 hour lecture; 6 hours lab; 3 semester hours.

# Advanced Manufacturing

## Degrees Offered

- Graduate Certificate in Advanced Manufacturing
- Graduate Certificate in Smart Manufacturing
- Master of Science in Advanced Manufacturing (Non-Thesis)

## Program Description

The Advanced Manufacturing Program provides graduates and professional students with the practical, interdisciplinary skills to apply cutting-edge manufacturing techniques to a wide range of industries, including aerospace, biomedical, defense and energy, among others.

This program highlights the design, materials and data aspects of advanced manufacturing with an emphasis on additive manufacturing of structural materials.

## Program Requirements - Advanced Manufacturing

## Graduate Certificate (12 credit hours)

The graduate certificate requirements are outlined below.

| | | |
|---|---|---|
| **Core Requirements** | | |
| AMFG401 | ADDITIVE MANUFACTURING | 3.0 |
| or AMFG501 | ADDITIVE MANUFACTURING | |
| **Select 2 of 3 of the Remaining Core Courses:** | | |
| AMFG531 | MATERIALS FOR ADDITIVE MANUFACTURING | 3.0 |
| AMFG421 | DESIGN FOR ADDITIVE MANUFACTURING | 3.0 |
| or AMFG521 | DESIGN FOR ADDITIVE MANUFACTURING | |
| AMFG511 | DATA DRIVEN ADVANCED MANUFACTURING | 3.0 |
| **Electives** | | |
| ELECT | Select electives from the Advanced Manufacturing list below | |
| Total Semester Hrs | | 12.0 |

Please note: Only 3 of the 12 credit hours can include coursework at the 400-level or lower to achieve the Graduate Certificate.

## MASTER OF SCIENCE, Non-Thesis (30 credit hours)

| | | |
|---|---|---|
| **Core Requirements:** | | |
| AMFG401 | ADDITIVE MANUFACTURING | 3.0 |
| or AMFG501 | ADDITIVE MANUFACTURING | |
| **Select 2 of 3 of the Remaining Core Courses:** | | |
| AMFG531 | MATERIALS FOR ADDITIVE MANUFACTURING | 3.0 |
| AMFG421 | DESIGN FOR ADDITIVE MANUFACTURING | 3.0 |
| or AMFG521 | DESIGN FOR ADDITIVE MANUFACTURING | |
| AMFG511 | DATA DRIVEN ADVANCED MANUFACTURING | 3.0 |
| **Electives:** | | |
| ELECT | Select electives from the Advanced Manufacturing list below Up to 6 hours may be replaced with project-based independent study | 21.0 |

## Mines' Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program (with uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any courses that count towards the graduate degree requirements as either "Required Coursework" or "Elective Coursework", as defined below, may be used for the purposes of double counting at the discretion of the advisor (MS Non-Thesis) or thesis committee (MS Thesis or PhD). These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit.

## Advanced Manufacturing Electives:

| | | |
|---|---|---|
| **Materials for Additive Manufacturing** | | |
| MEGN511 | FATIGUE AND FRACTURE | 3.0 |
| MEGN515 | COMPUTATIONAL MECHANICS | 3.0 |
| MLGN505 | MECHANICAL PROPERTIES OF MATERIALS | 3.0 |
| MTGN514 | DEFECT CHEMISTRY AND TRANSPORT PROCESSES IN CERAMIC SYSTEMS | 3.0 |
| MTGN531 | THERMODYNAMICS OF METALLURGICAL AND MATERIALS PROCESSING | 3.0 |
| MTGN536 | OPTIMIZATION AND CONTROL OF METALLURGICAL SYSTEMS | 3.0 |
| MTGN557 | SOLIDIFICATION | 3.0 |
| MTGN560 | ANALYSIS OF METALLURGICAL FAILURES | 3.0 |
| MTGN564 | ADVANCED FORGING AND FORMING | 3.0 |
| MTGN565 | MECHANICAL PROPERTIES OF CERAMICS AND COMPOSITES | 3.0 |
| MTGN580 | ADVANCED WELDING METALLURGY | 3.0 |
| MTGN583 | PRINCIPLES OF NON-DESTRUCTIVE TESTING AND EVALUATION | 3.0 |
| PHGN585 | NONLINEAR OPTICS | 3.0 |
| AMFG531 | MATERIALS FOR ADDITIVE MANUFACTURING | 3.0 |
| AMFG511 | DATA DRIVEN ADVANCED MANUFACTURING | 3.0 |
| AMFG421 | DESIGN FOR ADDITIVE MANUFACTURING | 3.0 |
| AMFG521 | DESIGN FOR ADDITIVE MANUFACTURING | 3.0 |
| ELECT | Electives As Approved By Advisor | |
| **Design for Additive Manufacturing** | | |
| FEGN525 | ADVANCED FEA THEORY & PRACTICE | 3.0 |
| FEGN526 | STATIC AND DYNAMIC APPLICATIONS IN FEA | 3.0 |
| FEGN527 | NONLINEAR APPLICATIONS IN FEA | 3.0 |
| FEGN528 | FEA FOR ADVANCED DESIGN APPLICATIONS | 3.0 |
| AMFG531 | MATERIALS FOR ADDITIVE MANUFACTURING | 3.0 |
| AMFG511 | DATA DRIVEN ADVANCED MANUFACTURING | 3.0 |
| AMFG421 | DESIGN FOR ADDITIVE MANUFACTURING | 3.0 |
| AMFG521 | DESIGN FOR ADDITIVE MANUFACTURING | 3.0 |
| AMFG4XX/5XX | LEAN MANUFACTURING | 3.0 |
| MEGN592 | RISK AND RELIABILITY ENGINEERING ANALYSIS AND DESIGN | 3.0 |
| CEEN401/501 | LIFE CYCLE ASSESSMENT | 3.0 |
| EBGN576 | MANAGING AND MARKETING NEW PRODUCT DEVELOPMENTS | 3.0 |

| | | |
|---|---|---|
| ELECT | Electives As Approved By Advisor | |
| **Data-Driven Materials Manufacturing** | | |
| CSCI507 | INTRODUCTION TO COMPUTER VISION | 3.0 |
| CSCI508 | ADVANCED TOPICS IN PERCEPTION AND COMPUTER VISION | 3.0 |
| CSCI575 | MACHINE LEARNING | 3.0 |
| EENG509 | SPARSE SIGNAL PROCESSING | 3.0 |
| EENG511 | CONVEX OPTIMIZATION AND ITS ENGINEERING APPLICATIONS | 3.0 |
| EENG515 | MATHEMATICAL METHODS FOR SIGNALS AND SYSTEMS | 3.0 |
| EENG517 | THEORY AND DESIGN OF ADVANCED CONTROL SYSTEMS | 3.0 |
| MATH530 | STATISTICAL METHODS I | 3.0 |
| MATH551 | COMPUTATIONAL LINEAR ALGEBRA | 3.0 |
| MEGN544 | ROBOT MECHANICS: KINEMATICS, DYNAMICS, AND CONTROL | 3.0 |
| MEGN545 | ADVANCED ROBOT CONTROL | 3.0 |
| MEGN587 | NONLINEAR OPTIMIZATION | 3.0 |
| MEGN588 | INTEGER OPTIMIZATION | 3.0 |
| MEGN688 | ADVANCED INTEGER OPTIMIZATION | 3.0 |
| AMFG531 | MATERIALS FOR ADDITIVE MANUFACTURING | 3.0 |
| AMFG421 | DESIGN FOR ADDITIVE MANUFACTURING | 3.0 |
| AMFG521 | DESIGN FOR ADDITIVE MANUFACTURING | 3.0 |
| AMFG511 | DATA DRIVEN ADVANCED MANUFACTURING | 3.0 |
| AMFG4XX/5XX | LEAN MANUFACTURING | 3.0 |
| ELECT | Electives As Approved By Advisor | |

## Program Requirements - Smart Manufacturing

## Graduate CERTIFICATE (12 CREDIT HOURS)

The graduate certificate program is targeted to train recent graduates, as well as professionals interested in expanding their knowledge and skills to address the opportunities and challenges in advanced manufacturing. A 12-credit hour, graduate certificate requires a set of four core courses taught by multiple departments and interdisciplinary programs on campus.

The Smart Manufacturing Graduate Certificate program is anchored by four signature core courses. Three technical skills-based courses focusing on Lean Manufacturing and Six-sigma, Life Cycle Assessment and Optimal Planning of Manufacturing Operations provide students with skillsets for implementing efficiency and optimization skillsets into any process in industry. All three of these courses are also tailored towards advanced manufacturing with real world examples, projects and analysis being performed in current manufacturing settings. The fourth core-course, EBGN 576 Product Management, will teach students how to implement change in their workplace with the new skillsets learned throughout the program. EBGN 576 focuses on bringing innovative processes, products and services to market—particularly in an engineering or technology field.

The Smart Manufacturing Graduate Certificate is offered fully online to accommodate working professionals outside the immediate geographic area. These courses are also available as elective courses in the current Advanced Manufacturing Masters (Non-Thesis) and Additive Manufacturing certificate programs.

The four-core courses in the Smart Manufacturing program explore the emerging skillsets of Lean Manufacturing, Life Cycle Assessment, Operations Research and Product/Process Development for creating the next generation of optimized manufacturing facilities, saving companies both time and money. Students and professionals enrolled in the professional certificate program will complete the four core courses found below:

| | | |
|---|---|---|
| AMFG422 | LEAN MANUFACTURING | 3.0 |
| or AMFG522 | LEAN MANUFACTURING | |
| CEEN401/501 | LIFE CYCLE ASSESSMENT | 3.0 |
| ORWE5XX | OPTIMAL PLANNING OF MANUFACTURING OPERATIONS | 3.0 |
| EBGN576 | MANAGING AND MARKETING NEW PRODUCT DEVELOPMENTS | 3.0 |
| Total Semester Hrs | | 12.0 |

Please note: Only 3 of the 12 credit hours can include coursework at the 400-level or lower to achieve the Graduate Certificate.

## Courses

**AMFG501. ADDITIVE MANUFACTURING. 3.0 Semester Hrs.**
(II) Additive Manufacturing (AM), also known as 3D Printing in the popular press, is an emerging manufacturing technology that will see widespread adoption across a wide range of industries during your career. Subtractive Manufacturing (SM) technologies (CNCs, drill presses, lathes, etc.) have been an industry mainstay for over 100 years. The transition from SM to AM technologies, the blending of SM and AM technologies, and other developments in the manufacturing world has direct impact on how we design and manufacture products. This course will prepare students for the new design and manufacturing environment that AM is unlocking. The graduate section of this course differs from the undergraduate section in that graduate students perform AM-related research. While students complete quizzes and homework, they do not take a midterm or final exam. Prerequisites: MEGN200 and MEGN201 or equivalent project classes. 3 hours lecture; 3 semester hours.

**AMFG511. DATA DRIVEN ADVANCED MANUFACTURING. 3.0 Semester Hrs.**
(I) Although focused on materials manufacturing, this course is intended for all students interested in experimental design and data informatics. It will include both directed assignments to reinforce the concepts and algorithms discussed in class and a term project that will encourage students to apply these concepts to a problem of their choosing. Some programming background would be beneficial but is not necessary; the basics of python and the sklearn machine learning toolkit will be covered in the first weeks of the course. 3 hours lecture; 3 semester hours.

**AMFG521. DESIGN FOR ADDITIVE MANUFACTURING. 3.0 Semester Hrs.**
(II) Design for Additive Manufacturing (DAM) introduces common considerations that must be addressed to successfully design or re-design parts for additive manufacturing methods. Industry-leading hardware and FEA software will be used to explore all phases of the DAM workflow, including topology optimization, additive process simulation, distortion compensation, and in-service performance. 3 hours lecture; 3 semester hours.

**AMFG522. LEAN MANUFACTURING. 3.0 Semester Hrs.**
Throughout the course, students will learn to apply skillsets to real world problems, focusing on lean and six-sigma principles and methodologies. The course is taught with a focus on the DMAIC structure of implementation (Define, Measure, Analyze, Improve and Control) for improving and implementing process efficiencies in industry. The course is split into three general subject areas; 1) Lean manufacturing principles, 2) six-sigma and statistical process control (SPC) methodologies and 3) Implementation techniques focusing on graphical and numerical representation of processes using R. Students will receive an in-depth overview of Lean manufacturing principles and will perform case studies at local industries to implement learned skill-sets. Next, students will step-through several hands-on activities using real products to investigate six-sigma and perform SPC analysis, identifying shifts in process data and learning how to shift processes into capable processes. Lastly, students will learn about various implementation techniques for industry and will perform an in-depth analysis of the course topics based on the industry tours performed.

**AMFG531. MATERIALS FOR ADDITIVE MANUFACTURING. 3.0 Semester Hrs.**
(II) This course will cover various structural materials used in additive manufacturing (AM) processes. Focus will be on polymer, ceramic, and metallic compositions. General chemistry of each material will be covered with additional focus on the behavior of these materials when processed using AM. The course will span the entire AM lifecycle from feedstock fabrication to fabrication by AM to post processing and inspection of as-fabricated material. Students will have hands-on exposure to AM processes and will conduct laboratory studies of AM material properties. Additionally, students will conduct a semester-long research project exploring some aspect of AM materials. 3 hours lecture; 3 semester hours.

**AMFG598. SPECIAL TOPICS IN ADVANCED MANUFACTURING. 1-6 Semester Hr.**
(I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: none. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

## Director and Professor of Practice

Craig A. Brice

# Data Science

## Degrees Offered

- Master of Science in Data Science (Non-Thesis)
- Graduate Certificate in Data Science - Statistical Learning
- Graduate Certificate in Data Science - Earth Resources
- Graduate Certificate in Petroleum Data Analytics
- Graduate Certificate in Business Analytics
- Post-Baccalaureate Certificate in Data Science - Foundations
- Post Baccalaureate Certificate in Data Science - Computer Science

## Program Description

The Master of Data Science (Non-Thesis) program is designed to give candidates a foundation in statistics and computer science and also provide knowledge in a particular application domain of science or engineering. The balance between these three elements is a strength of the program and can prepare candidates for Data Science careers in industry, government, or for further study at the PhD level. Throughout is an emphasis on working in teams, creative problem solving, and professional development.

The certificates are designed for college graduates and professionals interested in the emerging field of Data Science.

## Program Requirements

## Master of Data Science (Non-Thesis)

The field of Data Science draws on elements of computer science, statistics and interdisciplinary applications to address the unique needs of gaining knowledge and insight through data analysis. This masters non-thesis program is designed to give candidates a foundation in statistics and computer science and also provide knowledge in a particular application domain of science or engineering. The balance between these three elements is a strength of the program and can prepare candidates for Data Science careers in industry, government, or for further study at the PhD level. Moreover, the coursework will be flexible and tailored to each candidate. For example, the program will allow a candidate to increase his/her skills in data analytics while developing a focused area of application or alternatively allow a candidate with depth in an area of application to gain skills in statistics and computer science.

This program will follow a 3 X 3 + 1 design: three modules and a mini-module.

## Modules (Each consisting of three 3 credit courses)

- *Data Modeling and Statistical Learning*
  - *MATH530: Statistical Methods*
  - *MATH560: Statistical Learning I*
  - *MATH561: Statistical Learning II*
- *Machine Learning, Data Processing and Algorithms, and Parallel Computation*
  - *CSCI303: Introduction to Data Science*
  - *CSCI470: Introduction to Machine Learning*
  - *CSCI575: Machine Learning OR CSCI563: Parallel Computing for Scientists and Engineers*
- *Individualized and Domain Specific Coursework*
  - *Example Modules:*

    *Electrical Engineering: EENG411 (Digital Signal Processing); EENG509 (Sparse Signal Processing); EENG511 (Convex Optimization and its Engineering Applications); EENG515 (Mathematical Methods for Signals and Systems); and/or EEGN519 (Estimation Theory and Kalman Filtering)*

    *Geophysics: GPGN533 (Geophysical Data Integration & Geostatistics); GPGN570 (Applications of Satellite Remote Sensing); and/or GPGN605 (Inversion Theory)*

## Mini-module (Comprising three 1 credit courses)

- *Professional Development*
  - *SYGN502: Introduction to Research Ethics*
  - *SYGN5XX: Leadership and Teamwork*
  - *LICM501: Professional Oral Communication*

| | | | | |
|---|---|---|---|---|
| **First Year** | | | | |
| **Fall** | | **lec** | **lab** | **sem.hrs** |
| CSCI303 | INTRODUCTION TO DATA SCIENCE | | | 3.0 |
| CSCI470 | INTRODUCTION TO MACHINE LEARNING | | | 3.0 |
| MATH530 | STATISTICAL METHODS I | | | 3.0 |
| ELECT | Elective Approved by Program | | | 3.0 |
| | | | | 12.0 |
| **Spring** | | **lec** | **lab** | **sem.hrs** |
| CSCI575 | MACHINE LEARNING | | | 3.0 |
| MATH560 | INTRODUCTION TO KEY STATISTICAL LEARNING METHODS I | | | 3.0 |
| ELECT | Elective Approved by Program | | | 3.0 |
| LICM501 | PROFESSIONAL ORAL COMMUNICATION | | | 1.0 |
| | | | | 10.0 |
| **Second Year** | | | | |
| **Fall** | | **lec** | **lab** | **sem.hrs** |
| MATH561 | INTRODUCTION TO KEY STATISTICAL LEARNING METHODS II | | | 3.0 |
| ELECT | Elective Approved by Program | | | 3.0 |
| SYGN502 | INTRODUCTION TO RESEARCH ETHICS | | | 1.0 |
| SYGN5XX | LEADERSHIP AND TEAMWORK | | | 1.0 |
| | | | | 8.0 |

Total Semester Hrs: 30.0

**Electives for the third module can be designed by the student but the plan needs to be approved by the program curriculum committee. Although this individualized module can draw on graduate courses from across the university, two specific examples from engineering and geophysics are given below:

Electrical Engineering Module: EENG411 (Digital Signal Processing); EENG509 (Sparse Signal Processing); EENG511 (Convex Optimization and its Engineering Applications); EENG515 (Mathematical Methods for Signals and Systems); and/or EEGN519 (Estimation Theory and Kalman Filtering)

Geophysics Module: GPGN533 (Geophysical Data Integration & Geostatistics); GPGN570 (Applications of Satellite Remote Sensing); and/or GPGN605 (Inversion Theory)

## Mines Combined Undergraduate / Graduate Degree Program

The Master of Science in Data Science (MSDS) program allows students to work on a Bachelor of Science and a Master of Science simultaneously. The MSDS requires 30 credit hours of coursework at the graduate level. Students enrolled within the combined program may choose up to six credits of coursework at the 400 or 500 level to "double-count"; that is, apply towards both their Bachelor of Science degree requirements and their Master of Science degree requirements. Courses that will be double counted need to be preapproved by the Director of Data Science or their graduate advisor, and must be successfully completed with a grade of a B or better.

## Program Requirements

## Certificate Programs in Data Science

There are five Certificates in Data Science.  Applicants for each are required to have an undergraduate degree to be admitted into the Certificate programs. Course prerequisites, if any, are noted for each Certificate program.

Students working toward one of the Data Science Certificates are required to successfully complete 12 credit hours, as detailed below for each Certificate.The courses taken for the Certificates can be used towards a Master's or PhD degree at Mines, however courses used for one Data Science Certificate cannot also be counted toward another Data Science Certificate.

## Post Baccalaureate Certificate in Data Science - Foundations (12 credit hours)

The Data Science - Foundations Post Baccalaureate Certificate is an online or residential program focusing on the foundational concepts in statistics and computer science that support the explosion of new methods for interpreting data in its many forms. The Certificate balances an introduction to data science with teaching basic skills in applying methods in statistics and machine learning to analyze data.  Students will gain a perspective on the kinds of problems that can be solved by data intensive methods and will also acquire new analysis skills outside of the certificate. Moreover, the coursework will cover a broad range of applications, making it relevant for varied scientific and engineering domains.

Applicants must have completed the following courses, or their equivalents, with a B- or better:  CSCI261 and CSCI262 Data Structures, MATH332 Linear Algebra and MATH334 Introduction to Probability.

| | | |
|---|---|---|
| DSCI403/ CSCI303 | INTRODUCTION TO DATA SCIENCE | 3.0 |
| DSCI/CSCI470 | INTRODUCTION TO MACHINE LEARNING | 3.0 |
| DSCI/MATH530 | STATISTICAL METHODS I | 3.0 |
| DSCI/MATH560 | INTRODUCTION TO KEY STATISTICAL LEARNING METHODS I | 3.0 |

## Post Baccalaureate Certificate in Data Science - Computer Science (12 credit hours)

The Data Science - Computer Science Post Baccalaureate Certificate is an online or residential program focusing on data science concepts within computer science (e.g., computational techniques and machine learning) plus prerequisite knowledge (e.g., probability and regression). The aim of this new certificate is to help students develop an essential skill set in data analytics, including (1) deriving predictive insights by applying advanced statistics, modeling, and programming skills, (2) acquiring in-depth knowledge of machine learning and computational techniques, and (3) unearthing important questions and intelligence for a range of industries, from product design to finance.

Applicants must have completed the following courses, or their equivalents, with a B- or better:  CSCI261 and CSCI262 Data Structures, MATH213 Calculus III and MATH332 Linear Algebra.  MATH530 Statistical Methods I, will serve as the MATH201 Probability and Statistics prerequisite for the two machine learning courses of the certificate (CSCI470/DSCI470 Introduction to Machine Learning and CSCI575/ DSCI575 Machine Learning).

| | | |
|---|---|---|
| DSCI403/ CSCI303 | INTRODUCTION TO DATA SCIENCE | 3.0 |
| DSCI/MATH530 | STATISTICAL METHODS I | 3.0 |
| DSCI/CSCI470 | INTRODUCTION TO MACHINE LEARNING | 3.0 |
| DSCI/CSCI575 | MACHINE LEARNING | 3.0 |

## Graduate Certificate in Data Science - Statistical Learning (12 credit hours)

The Data Science - Statistical Learning Graduate Certificate is an online or residential program focusing on statistical methods for interpreting complex data sets and quantifying the uncertainty in a data analysis. The Certificate also includes gaining new skills in computer science but is grounded in statistical models for data, also termed statistical learning, rather than algorithmic approaches.  Students will develop an essential skill set in statistical methods most commonly used in data science along with the understanding of the methods' strengths and weaknesses. Moreover, the coursework will cover a broad range of applications making it relevant for varied scientific and engineering domains.

Applicants must have completed the following courses, or their equivalents, with a B- or better:  CSCI261 and CSCI262 Data Structures, MATH332 Linear Algebra and MATH334 Introduction to Probability.

| | | |
|---|---|---|
| DSCI403/ CSCI303 | INTRODUCTION TO DATA SCIENCE | 3.0 |
| DSCI/MATH530 | STATISTICAL METHODS I | 3.0 |
| DSCI/MATH560 | INTRODUCTION TO KEY STATISTICAL LEARNING METHODS I | 3.0 |
| DSCI/MATH561 | INTRODUCTION TO KEY STATISTICAL LEARNING METHODS II | 3.0 |

## Graduate Certificate in Data Science - Earth Resources (12 credit hours)

The Graduate Certificate in Data Science - Earth Resources is an online program building on the foundational concepts in data science as it pertains to managing surface and subsurface Earth resources and on specific applications (use cases) from the petroleum and minerals industries as well as water resource monitoring and remote sensing of Earth change. The Certificate includes one core introductory Data Science course, two courses specific to Earth resources and one elective.

| | | |
|---|---|---|
| DSCI403/ CSCI303 | INTRODUCTION TO DATA SCIENCE | 3.0 |
| GEOL557 | EARTH RESOURCE DATA SCIENCE 1: FUNDAMENTALS | 3.0 |
| GEOL558 | EARTH RESOURCE DATA SCIENCE 2: APPLICATIONS AND MACHINE-LEARNING | 3.0 |
| ELECTIVE | (1) ELECTIVE FROM LIST BELOW | 3.0 |

**Graduate Certificate in Data Science - Earth Resources Electives (select ONE (1) from the list below):**

| | | |
|---|---|---|
| **Geospatial Focus:** | | |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEGN579 | PYTHON SCRIPTING FOR GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| **Petroleum Focus:** | | |
| GPGN519 | ADVANCED FORMATION EVALUATION | 3.0 |
| GPGN547 | PHYSICS, MECHANICS, AND PETROPHYSICS OF ROCKS | 3.0 |
| GPGN558 | SEISMIC DATA INTERPRETATION AND QUANTITATIVE ANALYSIS | 3.0 |
| GPGN651 | ADVANCED SEISMOLOGY | 3.0 |
| PEGN522 | ADVANCED WELL STIMULATION | 3.0 |
| PEGN551 | PETROLEUM DATA ANALYTICS - FUNDAMENTALS | 3.0 |
| **Mining Focus:** | | |
| MNGN548 | INTEGRATED INFORMATION AND MINE SYSTEMS MANAGEMENT | 3.0 |
| **Hydrology Focus:** | | |
| CEEN581 | WATERSHED SYSTEMS MODELING | 3.0 |
| **Additional Options:** | | |
| DSCI/MATH530 | STATISTICAL METHODS I | 3.0 |
| EBGN525 | BUSINESS ANALYTICS | 3.0 |

## Graduate Certificate in Petroleum Data Analytics (12 credit hours)

The Graduate Certificate in Petroleum Data Analytics is an online program building on the foundational concepts in statistics and focusing on the data foundation of the oil and gas industry, the challenges of Big Data to oilfield operations and on specific applications (use cases) for petroleum analytics. The Certificate includes two core introductory Data Science courses and two course specific to petroleum engineering.

| | | |
|---|---|---|
| DSCI/MATH530 | STATISTICAL METHODS I | 3.0 |
| DSCI403/ CSCI303 | INTRODUCTION TO DATA SCIENCE | 3.0 |
| PEGN551 | PETROLEUM DATA ANALYTICS - FUNDAMENTALS | 3.0 |
| PEGN552 | PETROLEUM DATA ANALYTICS - APPLICATIONS | 3.0 |

## Program Requirements

## Graduate Certificate in Business Analytics

The certificate requirements are to complete the following three courses:

| | | |
|---|---|---|
| EBGN525 | BUSINESS ANALYTICS | 3.0 |
| EBGN560 | DECISION ANALYTICS | 3.0 |
| EBGN571 | MARKETING ANALYTICS | 3.0 |

Course substitutions can be approved on a case-by-case basis by the certificate directors. Completing the certificate will also position students to complete either the MS ETM degree or MS in Data Science degree as all the certificate courses can be applied to either degree.

## Courses

**DSCI403. INTRODUCTION TO DATA SCIENCE. 3.0 Semester Hrs.**
This course will teach students the core skills needed for gathering, cleaning, organizing, analyzing, interpreting, and visualizing data. Students will learn basic SQL for working with databases, basic Python programming for data manipulation, and the use and application of statistical and machine learning toolkits for data analysis. The course will be primarily focused on applications, with an emphasis on working with real (non-synthetic) datasets. Prerequisite: CSCI101 or CSCI261.

**DSCI470. INTRODUCTION TO MACHINE LEARNING. 3.0 Semester Hrs.**
The goal of machine learning is to build computer systems that improve automatically with experience, which has been successfully applied to a variety of application areas, including, for example, gene discovery, financial forecasting, and credit card fraud detection. This introductory course will study both the theoretical properties of machine learning algorithms and their practical applications. Students will have an opportunity to experiment with machine learning techniques and apply them to a selected problem in the context of term projects. Prerequisite: MATH201, MATH332.

**DSCI530. STATISTICAL METHODS I. 3.0 Semester Hrs.**
Introduction to probability, random variables, and discrete and continuous probability models. Elementary simulation. Data summarization and analysis. Confidence intervals and hypothesis testing for means and variances. Chi square tests. Distribution-free techniques and regression analysis. Prerequisite: MATH213 or equivalent.

**DSCI560. INTRODUCTION TO KEY STATISTICAL LEARNING METHODS I. 3.0 Semester Hrs.**
Part one of a two-course series introducing statistical learning methods with a focus on conceptual understanding and practical applications. Methods covered will include Introduction to Statistical Learning, Linear Regression, Classification, Resampling Methods, Basis Expansions, Regularization, Model Assessment and Selection.

**DSCI561. INTRODUCTION TO KEY STATISTICAL LEARNING METHODS II. 3.0 Semester Hrs.**
Part two of a two course series introducing statistical learning methods with a focus on conceptual understanding and practical applications. Methods covered will include Non-linear Models, Tree-based Methods, Support Vector Machines, Neural Networks, Unsupervised Learning.

**DSCI575. MACHINE LEARNING. 3.0 Semester Hrs.**
The goal of machine learning research is to build computer systems that learn from experience and that adapt to their environments. Machine learning systems do not have to be programmed by humans to solve a problem; instead, they essentially program themselves based on examples of how they should behave, or based on trial and error experience trying to solve the problem. This course will focus on the methods that have proven valuable and successful in practical applications. The course will also contrast the various methods, with the aim of explaining the situations in which each is most appropriate. Prerequisite: CSCI262, MATH201, MATH332.

## Professors

Douglas Nychka, Applied Mathematics & Statistics, Professor

Paul Sava, Geophysics, Professor

## Associate professors

Dorit Hammerling, Applied Mathematics & Statistics, Associate Professor

Michael Wakin, Electrical Engineering, Associate Professor

Hua Wang, Computer Science, Associate Professor

## Teaching Associate Professor

Wendy Fisher, Computer Science, Teaching Associate Professor

# Finite Element Analysis (FEA)

## Degrees Offered

- Graduate Certificate - FEA Professional

## Program Description

The Graduate Certificate - FEA Professional is a fully-online graduate-level certificate program that teaches advanced skills in finite element analysis for structural applications. The program has been designed to train recent graduates or mid-career professionals with at least a BS in engineering, computer science, or applied engineering physics who are interested in careers and/or opportunities in design, product development, or applied research. The program leverages industry-leading software to empower students with the skills and experience to drive innovation in their chosen field. Our courses help students build a foundation of practical knowledge focused on key fundamentals of applied computational mechanics complemented by the perfect balance of theoretical background. The fundamentals learned here may be applicable across a broad range of industries. Upon completion of the program, graduates will have the skills to: (a) earn software-specific endorsements/certifications for industry-leading products such as Abaqus, SolidWorks Simulation, ANSYS; (b) drive innovation through the effective application of simulation tools for ideation and design verification; (c) leverage simulation to reduce physical testing in new product development (NPD) and reduce time to market; (d) exploit parametric simulation, DOE, and optimization to reveal more and better R&D solutions; (e) identify CTQ's in your development or applied research projects and quantify impact on all relevant outcome metrics; (f) execute, review, and manage simulation strategies for your NPD or applied research pipeline; and (g) spec software tools and training for your team.

**Program Director and Associate Professor**

Anthony J. Petrella

## Program Requirements

The Graduate Certificate - FEA Professional requires a set of three core courses (Table 1) and one elective chosen from selected relevant online courses (Table 2). Elective options will continue to expand as the program matures.

The student must complete the following three core courses.

| | | |
|---|---|---|
| FEGN525 | ADVANCED FEA THEORY & PRACTICE | 3.0 |
| FEGN526 | STATIC AND DYNAMIC APPLICATIONS IN FEA | 3.0 |
| FEGN527 | NONLINEAR APPLICATIONS IN FEA | 3.0 |

The student must complete one of the following elective courses (3 semester hrs).

| | | |
|---|---|---|
| FEGN528 | FEA FOR ADVANCED DESIGN APPLICATIONS | 3.0 |
| AMFG521 | DESIGN FOR ADDITIVE MANUFACTURING | 3.0 |

## Transfer Credits

Transfer credits are not currently accepted to satisfy requirements for the Graduate Certificate - FEA Professional.

## Prerequesites

A baccalaureate degree in engineering, computer science, a physical science, or mathematics is required.

## Courses

**FEGN525. ADVANCED FEA THEORY & PRACTICE. 3.0 Semester Hrs.**
This course examines the theory and practice of finite element analysis. Direct methods of deriving the FEA governing equations are addressed as well as more advanced techniques based on virtual work and variational methods. Common 1D, 2D, and 3D element formulations are derived, and key limitations examined. Matlab is used extensively to build intuition for FEA solution methods and students will create their own 2D FEA code by the end of the course. The commercial FEA software Abaqus is introduced with hands-on examples and Matlab solutions are compared to Abaqus for model validation.

**FEGN526. STATIC AND DYNAMIC APPLICATIONS IN FEA. 3.0 Semester Hrs.**
This course emphasizes proficiency with commercial FEA software for solution of practical static, quasistatic, and dynamic structural problems. Common 1D, 2D, and 3D elements are examined in the context of linear solution techniques. Students will explore efficient methods for model construction and solution with commercial tools (the Abaqus FEA software). Emphasis will also be placed on verification, validation, and reporting standards for effective application of FEA software tools. Online course. Prerequisite: FEGN525.

**FEGN527. NONLINEAR APPLICATIONS IN FEA. 3.0 Semester Hrs.**
This course explores common nonlinearities frequently encountered in structural applications of FEA. Students will gain proficiency in modeling geometric nonlinearity (large strains), boundary nonlinearity due to contact, and material nonlinearity (creep, rate dependence, plasticity, temperature effects, residual stress). The commercial FEA software Abaqus is used for hands-on experience. Online course. Prerequisite: FEGN526.

**FEGN528. FEA FOR ADVANCED DESIGN APPLICATIONS. 3.0 Semester Hrs.**
In this course students will learn the automation tools and methods necessary for effective application of FEA on advanced design problems. Strategies for parametric analysis, performance optimization, and consideration of statistical uncertainty will be examined using Python scripting and commercial automation software. Online course. Prerequisite: FEGN526.

# Geochemistry

## Degrees Offered

- Professional Masters in Environmental Geochemistry
- Master of Science (Geochemistry)
- Doctor of Philosophy (Geochemistry)

## Program Description

The Graduate Program in Geochemistry is an interdisciplinary program with the mission to educate students whose interests lie at the intersection of the geological and chemical sciences. The Geochemistry Program consists of two subprograms, administering two M.S. and Ph.D. degree tracks and one Professional Master's (non-thesis) degree program. The Geochemistry (GC) degree track pertains to the history and evolution of the Earth and its features, including but not limited to the chemical evolution of the crust and mantle, geochemistry of energy and mineral resources, aqueous geochemistry and fluid-rock/fluid-mineral interactions and chemical mineralogy. The Environmental Biogeochemistry (EBGC) degree track pertains to the coupled chemical and biological processes of Earth's biosphere, and the changes in these processes caused by human activities.

## Master of Science and Doctor of Philosophy

## 1. Geochemistry degree track

## Prerequisites

Each entering student will have an entrance interview with members of the Geochemistry subprogram faculty. Since entering students may not be proficient in both areas, a placement examination in geology and/or chemistry may be required upon the discretion of the interviewing faculty. If a placement examination is given, the results may be used to establish deficiency requirements. Credit toward a graduate degree will not be granted for courses taken to fulfill deficiencies.

## Requirements

The Master of Science (Geochemistry degree track) requires a minimum of 36 semester hours including:

| | |
|---|---|
| Course work | 24.0 |
| Research credits | 12.0 |
| Total Semester Hrs | 36.0 |

To ensure breadth of background, the course of study for the Master of Science (Geochemistry degree track) must include:

| | | |
|---|---|---|
| CHGC503 | INTRODUCTION TO GEOCHEMISTRY | 3.0 |
| CHGC504 | METHODS IN GEOCHEMISTRY | 3.0 |
| Master of Science (Geochemistry) students select at least 8 credits of the following: | | |
| CHGC509 | INTRODUCTION TO AQUEOUS GEOCHEMISTRY | 3.0 |
| or CEEN550 | PRINCIPLES OF ENVIRONMENTAL CHEMISTRY | |
| CHGC514 | GEOCHEMISTRY THERMODYNAMICS AND KINETICS | 3.0 |
| GEGN530 | CLAY CHARACTERIZATION | 2.0 |
| GEGN586 | NUMERICAL MODELING OF GEOCHEMICAL SYSTEMS | 3.0 |
| GEOL512 | MINERALOGY AND CRYSTAL CHEMISTRY | 3.0 |
| GEOL513 | HYDROTHERMAL GEOCHEMISTRY | 3.0 |
| GEOL523 | REFLECTED LIGHT AND ELECTRON MICROSCOPY | 2.0 |
| GEOL535 | LITHO ORE FORMING PROCESSES | 1.0 |
| GEOL540 | ISOTOPE GEOCHEMISTRY AND GEOCHRONOLOGY | 3.0 |

Master of Science (Geochemistry degree track) students must also complete an appropriate thesis, based upon original research they have conducted. A thesis proposal and course of study must be approved by the student's thesis committee before the student begins substantial work on the thesis research.

The requirement for the Doctor of Philosophy (Geochemistry degree track) program will be established individually by a student's thesis committee, but must meet the minimum requirements presented below. The Doctor of Philosophy (Geochemistry degree track) program will require a minimum of 72 credit hours beyond the Bachelor degree. A total of 24 course credits beyond the Bachelor's degree are required, with at least 9 credit being completed at Mines.

Students who enter the PhD program with a thesis-based Master's degree may transfer up to 36 semester hours in recognition of the course work and research completed for that degree. At the discretion of the student's Thesis Committee, up to 24 semester hours of previous graduate-level course work (at Mines or elsewhere) can be applied towards the course requirement of the Doctor of Philosophy (Geochemistry degree track) program.

Doctor of Philosophy (Geochemistry degree track) students must take:

| | | |
|---|---|---|
| CHGC503 | INTRODUCTION TO GEOCHEMISTRY | 3.0 |
| CHGC504 | METHODS IN GEOCHEMISTRY | 3.0 |
| Students must also select at least 5 credits of the following: | | |
| CHGC509 | INTRODUCTION TO AQUEOUS GEOCHEMISTRY | 3.0 |
| CHGC514 | GEOCHEMISTRY THERMODYNAMICS AND KINETICS | 3.0 |
| GEGN530 | CLAY CHARACTERIZATION | 2.0 |
| GEGN586 | NUMERICAL MODELING OF GEOCHEMICAL SYSTEMS | 3.0 |
| GEOL512 | MINERALOGY AND CRYSTAL CHEMISTRY | 3.0 |
| GEOL513 | HYDROTHERMAL GEOCHEMISTRY | 3.0 |
| GEOL523 | REFLECTED LIGHT AND ELECTRON MICROSCOPY | 2.0 |
| GEOL535 | LITHO ORE FORMING PROCESSES | 1.0 |
| GEOL540 | ISOTOPE GEOCHEMISTRY AND GEOCHRONOLOGY | 3.0 |

Doctor of Philosophy (Geochemistry degree track) students must also complete an appropriate thesis, based upon original research they have conducted. A thesis proposal and course of study must be approved by the student's thesis committee before the student begins substantial work on the thesis research.

Master of Science (Geochemistry degree track) will be expected to give one pubic seminar on their research and Doctor of Philosophy (Geochemistry degree track) students are required to give at least one public seminar in addition to their thesis defense presentation.

## 2. Environmental Biogeochemistry (EBGC) degree track

### Prerequisites

A candidate for an MS or PhD in the EBGC degree track should have an undergraduate science or engineering degree with coursework including multivariable calculus, two semesters each of physics and chemistry, and one semester each of biology and earth science. Applicants who do not fulfill these requirements may still be admitted, but will need to undergo an entrance interview to establish deficiency requirements. Credit toward a graduate degree will not be given for undergraduate courses taken to fulfill deficiencies.

### Requirements

**Required Curriculum:** A thesis proposal and thesis are required for all MS and PhD degrees in the EBGC degree track. MS thesis advisors (or at least one co-advisor) must be members of the EBGC subprogram. PhD thesis committees must have a total of at least four members. PhD advisors (or at least one of two co-advisors) and one additional committee member must be members of the EBGC subprogram. MS students will be expected to give one public seminar on their research; PhD students are required to give at least one in addition to their thesis defense presentation.

In addition, both MS and PhD students in the EBGC degree track must complete the following coursework:

| | | |
|---|---|---|
| 1. Two required classes: | | |
| CHGC503 | INTRODUCTION TO GEOCHEMISTRY | 3.0 |
| CHGC504 | METHODS IN GEOCHEMISTRY | 3.0 |
| 2. One chemistry-focused class, chosen from the following list: | | |
| CEEN550 | PRINCIPLES OF ENVIRONMENTAL CHEMISTRY | 3.0 |
| CEEN551 | ENVIRONMENTAL ORGANIC CHEMISTRY | 3.0 |
| CHGC509 | INTRODUCTION TO AQUEOUS GEOCHEMISTRY | 3.0 |
| 3. One biology-focused class chosen from the following list: | | |
| CEEN560 | MOLECULAR MICROBIAL ECOLOGY AND THE ENVIRONMENT | 3.0 |
| CEEN562 | ENVIRONMENTAL GEOMICROBIOLOGY | 3.0 |
| 4. One earth science-focused class chosen from the following list | | |
| CHGC514 | GEOCHEMISTRY THERMODYNAMICS AND KINETICS | 3.0 |
| GEGN530 | CLAY CHARACTERIZATION | 2.0 |
| GEGN586 | NUMERICAL MODELING OF GEOCHEMICAL SYSTEMS | 3.0 |

Total credits required for MS: 36

Total credits required for PhD: 72

The student's thesis committee may specify additional course requirements and makes final decisions regarding transfer credits.

*Students who enter the PhD program with a thesis-based Master's degree may transfer up to 36 semester hours in recognition of the course work and research completed for that degree. At the discretion of the student's Thesis Committee, up to 24 semester hours of previous graduate-level course work (at Mines or elsewhere) can be applied towards the course requirement of the Doctor of Philosophy (Geochemistry degree track) program*.

A total of 24 course credits are required with at least 9 credits being completed at Mines.

### Comprehensive Examination

Doctor of Philosophy (Geochemistry) students in both degree tracks must take a comprehensive examination. It is expected that this exam will be completed within three years of matriculation or after the bulk of course work is finished, whichever occurs earlier. This examination will be administered by the student's thesis committee and will consist of an oral and a written examination, administered in a format to be determined by the thesis committee. Two negative votes in the thesis committee constitute failure of the examination.

In case of failure of the comprehensive examination, a re-examination may be given upon the recommendation of the thesis committee and approval of the Dean of Graduate Studies. Only one re-examination may be given.

### Tuition

The Master of Science (Geochemistry) and Doctor of Philosophy (Geochemistry) programs have been admitted to the Western Regional Graduate Program. This entity recognizes the Geochemistry Program as unique in the region. Designation of the Geochemistry Program by Western Regional Graduate program allows residents of western states to enroll in the program at Colorado resident tuition rates. Eligible states include Alaska, Arizona, California ,Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, South Dakota, Utah, Washington and Wyoming.

## Professional Masters in Environmental Geochemistry

### Introduction

The Professional Masters in Environmental Geochemistry program is intended to provide:

1. an opportunity for Mines undergraduates to obtain, as part of a fifth year of study, a Master in addition to the Bachelor degree; and
2. additional education for working professionals in the area of geochemistry as it applies to problems relating to the environment.

This is a non-thesis Master degree program administered by the Environmental Biogeochemistry subprogram of the Geochemistry program, and may be completed as part of a combined degree program by individuals already matriculated as undergraduate students at Mines, or by individuals already holding undergraduate or advanced degrees and who are interested in a graduate program that does not have the traditional research requirement. The program consists primarily of coursework in geochemistry and allied fields with an emphasis on environmental applications. No research is required though the program does allow for independent study, professional development, internship, and cooperative experience.

### Application

Undergraduate students at Mines must declare an interest during their third year to allow for planning of coursework that will apply towards the program. These students must have an overall GPA of at least 3.0. Students majoring in other departments besides the Department of

Geology and Geological Engineering and the Department of Chemistry and Geochemistry may want to decide on the combined degree program option earlier to be sure prerequisites are satisfied. Applicants other than Mines undergraduates who are applying for this non-thesis Master degree program must follow the same procedures that all prospective graduate students follow. However, the requirement of the general GRE may be waived.

## Prerequisites

Each entering student will have an entrance interview with members of the Geochemistry faculty. Each department recognizes that entering students may not be proficient in both areas. A placement examination in geology and/or chemistry may be required upon the discretion of the interviewing faculty. If a placement examination is given, the results may be used to establish deficiency requirements. Credit toward a graduate degree will not be granted for courses taken to fulfill deficiencies.

## Requirements

A minimum of 30 credit hours are required, with an overall GPA of at least 3.0. The overall course requirements will depend on the background of the individual, but may be tailored to professional objectives.

A 9 credit-hour core program consists of:

| | | |
|---|---|---|
| CHGC503 | INTRODUCTION TO GEOCHEMISTRY | 3.0 |
| CHGC509 | INTRODUCTION TO AQUEOUS GEOCHEMISTRY | 3.0 |
| GEGN466 | GROUNDWATER ENGINEERING * | 3.0 |
| Total Semester Hrs | | 9.0 |

In addition, 15 credit hours must be selected from the list below, representing the following core areas: geochemical methods, geographic information system, geological data analysis, groundwater engineering or modeling, hydrothermal geochemistry, isotope geochemistry, physical chemistry, microbiology, mineralogy, organic geochemistry, and thermodynamics. This selection of courses must include at least one laboratory course.

| | | |
|---|---|---|
| CEEN560 | MOLECULAR MICROBIAL ECOLOGY AND THE ENVIRONMENT | 3.0 |
| CHGC504 | METHODS IN GEOCHEMISTRY | 3.0 |
| CHGC555 | ENVIRONMENTAL ORGANIC CHEMISTRY | 3.0 |
| CHGN503 | ADV PHYSICAL CHEMISTRY I | 3.0 |
| GEGN530 | CLAY CHARACTERIZATION | 2.0 |
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEGN581 | ANALYTICAL HYDROLOGY | 3.0 |
| GEGN583 | MATHEMATICAL MODELING OF GROUNDWATER SYSTEMS | 3.0 |
| GEGN586 | NUMERICAL MODELING OF GEOCHEMICAL SYSTEMS | 3.0 |
| GEOL535 | LITHO ORE FORMING PROCESSES | 1.0 |
| GEOL540 | ISOTOPE GEOCHEMISTRY AND GEOCHRONOLOGY | 3.0 |

An additional 6 credit-hours of free electives may be selected to complete the 30 credit-hour requirement. Free electives may be selected from the course offerings of the Department of Geology and Geological Engineering, the Department of Chemistry and Geochemistry, or the Department of Civil and Environmental Engineering, and may also be independent study credits taken to fulfill a research cooperative, or other professional development experience. A course program will be designed in advanced through consultation between the student and an advisor from the Geochemistry Committee of the Whole.

## Mines' Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any 400+ level courses that count towards the undergraduate degree requirements as "Elective Coursework" or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a "B-" or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

## Courses

**CHGC503. INTRODUCTION TO GEOCHEMISTRY. 3.0 Semester Hrs.**
(I) A comprehensive introduction to the basic concepts and principles of geochemistry, coupled with a thorough overview of the related principles of thermodynamics. Topics covered include: nucleosynthesis, origin of earth and solar system, chemical bonding, mineral chemistry, elemental distributions and geochemical cycles, chemical equilibrium and kinetics, isotope systematics, and organic and biogeochemistry. Prerequisite: Introductory chemistry, mineralogy and petrology. 3 hours lecture; 3 semester hours.

**CHGC504. METHODS IN GEOCHEMISTRY. 3.0 Semester Hrs.**
(II) Field sampling of natural earth materials including rocks, soils, sediments, and waters. Preparation of naturally heterogeneous materials, digestions, and partial chemical extractions. Principles of instrumental analysis including trace elemental analysis by ICP-atomic spectroscopy, isotope analysis by ICP-MS, EM/X-ray methods, and chromatography. Quality assurance and quality control. Interpretation and assessment of geochemical data using statistical methods. Course format is hands-on, project oriented. Prerequisite: Graduate standing in geochemistry or environmental science and engineering. 2 hours lecture, 3 hours lab; 3 semester hours.

**CHGC505. INTRODUCTION TO ENVIRONMENTAL CHEMISTRY. 3.0 Semester Hrs.**
Equivalent with CHGN403,
(II) Processes by which natural and anthropogenic chemicals interact, react, and are transformed and redistributed in various environmental compartments. Air, soil, and aqueous (fresh and saline surface and groundwaters) environments are covered, along with specialized environments such as waste treatment facilities and the upper atmosphere. Meets with CHGN403. CHGN403 and CHGC505 may not both be taken for credit. Prerequisites: GEGN101, CHGN122 and CHGN209 or CBEN210. 3 hours lecture; 3 semester hours.

**CHGC506. WATER ANALYSIS LABORATORY. 2.0 Semester Hrs.**
Instrumental analysis of water samples using spectroscopy and chromatography. Methods for field collection of water samples and field measurements. The development of laboratory skills for the use of ICP-AES, HPLC, ion chromatography, and GC. Laboratory techniques focus on standard methods for the measurement of inorganic and organic constituents in water samples. Methods of data analysis are also presented. Prerequisite: Introductory chemistry, graduate standing. 3 hour laboratory, 1 hour lecture, 2 semester hours.

**CHGC509. INTRODUCTION TO AQUEOUS GEOCHEMISTRY. 3.0 Semester Hrs.**
Analytical, graphical and interpretive methods applied to aqueous systems. Thermodynamic properties of water and aqueous solutions. Calculations and graphical expression of acid-base, redox and solution-mineral equilibria. Effect of temperature and kinetics on natural aqueous systems. Adsorption and ion exchange equilibria between clays and oxide phases. Behavior of trace elements and complexation in aqueous systems. Application of organic geochemistry to natural aqueous systems. Light stable and unstable isotopic studies applied to aqueous systems. Prerequisite: DCGN209 or equivalent. 3 hours lecture; 3 semester hours.

**CHGC511. GEOCHEMISTRY OF IGNEOUS ROCKS. 3.0 Semester Hrs.**
A survey of the geochemical characteristics of the various types of igneous rock suites. Application of major element, trace element, and isotope geochemistry to problems of their origin and modification. Prerequisite: Undergraduate mineralogy and petrology. 3 hours lecture; 3 semester hours. Offered alternate years.

**CHGC514. GEOCHEMISTRY THERMODYNAMICS AND KINETICS. 3.0 Semester Hrs.**
(II) Fundamental principles of classical thermodynamics and kinetics with specific application to the earth sciences. Volume-temperature ? pressure relationships for solids, liquids, gases and solutions. Energy and the First Law, Entropy and the Second and Third Laws. Gibbs Free Energy, chemical equilibria and the equilibrium constant. Solutions and activity-composition relationships for solids, fluids and gases. Phase equilibria and the graphical representation of equilibira. Application of the fundamentals of kinetics to geochemical examples. Prerequisite: Introductory chemistry, introductory thermodynamics, mineralogy and petrology. 3 hours lecture, 3 semester hours. Offered in alternate years.

**CHGC527. ORGANIC GEOCHEMISTRY OF FOSSIL FUELS AND ORE DEPOSITS. 3.0 Semester Hrs.**
A study of organic carbonaceous materials in relation to the genesis and modification of fossil fuel and ore deposits. The biological origin of the organic matter will be discussed with emphasis on contributions of microorganisms to the nature of these deposits. Biochemical and thermal changes which convert the organic compounds into petroleum, oil shale, tar sand, coal and other carbonaceous matter will be studied. Principal analytical techniques used for the characterization of organic matter in the geosphere and for evaluation of oil and gas source potential will be discussed. Laboratory exercises will emphasize source rock evaluation, and oil-source rock and oil-oil correlation methods. Prerequisite: CHGN221, GEGN438. 2 hours lecture; 3 hours lab; 3 semester hours. Offered alternate years.

**CHGC555. ENVIRONMENTAL ORGANIC CHEMISTRY. 3.0 Semester Hrs.**
A study of the chemical and physical interactions which determine the fate, transport and interactions of organic chemicals in aquatic systems, with emphasis on chemical transformations of anthropogenic organic contaminants. Prerequisites: A course in organic chemistry and CHGN503, Advanced Physical Chemistry or its equivalent. Offered in alternate years. 3 hours lecture; 3 semester hours.

**CHGC562. MICROBIOLOGY AND THE ENVIRONMENT. 3.0 Semester Hrs.**
This course will cover the basic fundamentals of microbiology, such as structure and function of procaryotic versus eucaryotic cells; viruses; classification of micro-organisms; microbial metabolism, energetics, genetics, growth and diversity; microbial interactions with plants, animals, and other microbes. Additional topics covered will include various aspects of environmental microbiology such as global biogeochemical cycles, bioleaching, bioremediation, and wastewater treatment. Prerequisite: ESGN301. 3 hours lecture, 3 semester hours. Offered alternate years.

**CHGC563. ENVIRONMENTAL MICROBIOLOGY. 2.0 Semester Hrs.**
An introduction to the microorganisms of major geochemical importance, as well as those of primary importance in water pollution and waste treatment. Microbes and sedimentation, microbial leaching of metals from ores, acid mine water pollution, and the microbial ecology of marine and freshwater habitats are covered. Prerequisite: none. 1 hour lecture, 3 hours lab; 2 semester hours. Offered alternate years.

**CHGC564. BIOGEOCHEMISTRY AND GEOMICROBIOLOGY. 3.0 Semester Hrs.**
Designed to give the student an understanding of the role of living things, particularly microorganisms, in the shaping of the earth. Among the subjects will be the aspects of living processes, chemical composition and characteristics of biological material, origin of life, role of microorganisms in weathering of rocks and the early diagenesis of sediments, and the origin of petroleum, oil shale, and coal. Prerequisite: none. 3 hours lecture; 3 semester hours.

**CHGC598. SPECIAL TOPICS. 1-6 Semester Hr.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**CHGC599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**CHGC698. SPECIAL TOPICS. 1-6 Semester Hr.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**CHGC699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

## Professors

Linda A. Figueroa, Civil and Environmental Engineering

Wendy J. Harrison, Geology and Geological Engineering

John McCray, Civil and Environmental Engineering

James F. Ranville, Chemistry

John R. Spear, Civil and Environmental Engineering

Bettina M. Voelker, Chemistry

Richard F. Wendlandt, Geology and Geological Engineering

## Associate Professors

Christopher P. Higgins, Civil and Environmental Engineering

Thomas Monecke, Geology and Geological Engineering

Alexis Navarre-Sitchler, Department of Geology and Geological Engineering

Jonathan O. Sharp, Civil and Environmental Engineering

## Assistant Professors

Alexander Gysi, Geology and Geological Engineering

## Professors Emeriti

John B. Curtis, Geology and Geological Engineering

Donald L. Macalady , Chemistry and Geochemistry

Patrick MacCarthy, Chemistry and Geochemistry

Samuel B. Romberger, Geology and Geological Engineering

Thomas R. Wildeman, Chemistry and Geochemistry

## Associate Professors Emeriti

L. Graham Closs, Geology and Geological Engineering

E. Craig Simmons, Chemistry and Geochemistry

# GIS & GeoInformatics

## Degrees Offered

- Master of Science in GIS & GeoInformatics (Non-Thesis)
- Graduate Certificate of GIS & GeoInformatics: Geospatial Information Technology
- Graduate Certificate of GIS & GeoInformatics: GIS for Geohazards Evaluation
- Graduate Certificate of GIS & GeoInformatics: GIS for Environmental Studies
- Graduate Certificate of GIS & GeoInformatics: GIS for Natural Resources Assessment

## Program Description

The interdisciplinary online program in Geographic Information System (GIS) and GeoInformatics focus on the applications of GIS technology, hands-on geospatial training, multi-criteria decision making, advanced application and quantitative analysis aspects of GIS and Remote Sensing (RS), and are directly aligned with Colorado School of Mines' focuses and strengths on Earth, Energy and Environment. Our programs will enhance students' quantitative geospatial data analysis skills, help the students get ahead of the technology curve, and enable professionals to advance their careers.

## Certificate and Degree Requirements

We offer four graduate certificates and a non-thesis Master's degree. The courses taken for certificate degrees can be used towards the Master's degree. These programs are available as a residential program on the Mines campus and an online one.

**The Graduate Certificate Programs in GIS & GeoInformatics** outlined below may be completed by individuals already holding an undergraduate or advanced degree or as a combined degree program by individuals already matriculated as undergraduate students at The Colorado School of Mines. The graduate certificate is comprised of:

| | |
|---|---|
| Course Work | 12.0 |
| Total Semester Hrs | 12.0 |

Up to 3.0 credit hours can be at the 300- or 400- level and the remainder will be 500 or 600 level as listed below.

There are four certificates with different specialization areas, namely Geospatial Information Technology, Geohazards Evaluation, Environmental Studies, and Natural Resources Assessment.

## Graduate Certificate of GIS & GeoInformatics: Geospatial Information Technology

Students working towards a Graduate Certificate of GIS & GeoInformatics with specialization in **Geospatial Information Technology** are required to take any four of the following courses:

| | | |
|---|---|---|
| GEGN542 | ADVANCED DIGITAL TERRAIN ANALYSIS | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEGN580 | APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEOSCIENCES | 3.0 |
| GEGN588 | ADVANCED GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| MNGN5XX | Big Data Analytics for Earth Resources Sciences and Engineering | 3.0 |
| CEEN501 | LIFE CYCLE ASSESSMENT | 3.0 |
| CSCI303 | INTRODUCTION TO DATA SCIENCE | 3.0 |

## Graduate Certificate of GIS & GeoInformatics: Geohazards Evaluation

Students working towards a Graduate Certificate of GIS & GeoInformatics with specialization in **Geohazards Evaluation** are required to take:

| | | |
|---|---|---|
| **Two Required Courses:** | | |
| GEGN542 | ADVANCED DIGITAL TERRAIN ANALYSIS | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| **And, any two of the following courses:** | | |
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| GEGN579 | PYTHON SCRIPTING FOR GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEGN580 | APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEOSCIENCES | 3.0 |
| GEGN588 | ADVANCED GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| MNGN5XX | Big Data Analytics for Earth Resources Sciences and Engineering | 3.0 |
| CEEN501 | LIFE CYCLE ASSESSMENT | 3.0 |

## Graduate Certificate of GIS & GeoInformatics: Environmental Studies

Students working towards a Graduate Certificate of GIS & GeoInformatics with specialization in **Environmental Studies** are required to take:

| | | |
|---|---|---|
| **Two Required Courses:** | | |
| CEEN581 | WATERSHED SYSTEMS MODELING | 3.0 |
| GEGN542 | ADVANCED DIGITAL TERRAIN ANALYSIS | 3.0 |
| **And, any two of the following courses:** | | |
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| GEGN579 | PYTHON SCRIPTING FOR GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEGN580 | APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEOSCIENCES | 3.0 |
| GEGN588 | ADVANCED GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| CEEN501 | LIFE CYCLE ASSESSMENT | 3.0 |
| CSCI303 | INTRODUCTION TO DATA SCIENCE | 3.0 |

## Graduate Certificate of GIS & GeoInformatics: Natural Resources Assessment

Students working towards a Graduate Certificate of GIS & GeoInformatics with specialization in **Natural Resources Assessment** are required to take:

| | | |
|---|---|---|
| **Two Required Courses:** | | |
| MNGN4XX | Mine Closure and Reclamation | 3.0 |
| MNGN5XX | Big Data Analytics for Earth Resources Sciences and Engineering | 3.0 |
| **And, any two of the following courses:** | | |

| | | |
|---|---|---|
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEGN579 | PYTHON SCRIPTING FOR GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEGN580 | APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEOSCIENCES | 3.0 |
| GEGN588 | ADVANCED GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| CEEN501 | LIFE CYCLE ASSESSMENT | 3.0 |

## The Master of Science (Non-Thesis) Program in GIS & GeoInformatics

The Master of Science (Non-Thesis) Program outlined below may be completed by individuals already holding an undergraduate or advanced degree or as a combined degree program by individuals already matriculated as undergraduate students at Colorado School of Mines. Courses taken while working on any of the four GIS & GeoInformatics graduate certificates can be applied to this Master of Science program. The program is comprised of:

| | | |
|---|---|---|
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| SYGN588 | GIS-BASED REAL WORLD LEARNING PROJECT | 6.0 |
| Core Course Work | | 21.0 |
| Total Semester Hrs | | 30.0 |

Up to 9.0 credit hours can be at the 300- or 400- level listed below and the remainder will be 500 or 600 level.

| | | |
|---|---|---|
| **All Master of Science (Non-Thesis) program will include the following core requirements:** | | |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| SYGN588 | GIS-BASED REAL WORLD LEARNING PROJECT | 6.0 |
| **And, any seven of the following courses:** | | |
| GEGN542 | ADVANCED DIGITAL TERRAIN ANALYSIS | 3.0 |
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| GEGN579 | PYTHON SCRIPTING FOR GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEGN580 | APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEOSCIENCES | 3.0 |
| GEGN588 | ADVANCED GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| CSCI303 | INTRODUCTION TO DATA SCIENCE | 3.0 |
| CEEN581 | WATERSHED SYSTEMS MODELING | 3.0 |
| MNGN4XX | Mine Closure and Reclamation | 3.0 |
| MNGN5XX | Big Data Analytics for Earth Resources Sciences and Engineering | 3.0 |
| CEEN501 | LIFE CYCLE ASSESSMENT | 3.0 |

## Mines Combined Undergraduate / Graduate Program

Students enrolled in Mine's Combined Undergraduate/Graduate Program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any courses that count towards the graduate degree requirements as either "Required Coursework" or "Elective Coursework", as defined below, may be used for the purposes of double counting at the discretion of the advisor (MS Non-Thesis) or thesis committee (MS Thesis or PhD). These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit.

## Program Director

Wendy Zhou, Associate Professor, Engineering Geology & GIS

## Program Associate Director

Sebnem Duzgun, Professor, Fred Banfield Endowed Chair in Mining Engineering

## Professors

Terri Hogue, Hydrology and Water Resources, Professor

Amy Landis, Civil and Environmental Engineering, Professor, Mines Presidential Fellow for Diversity

Kamini Singha, Hydrogeology, Professor, Fryrear Chairs for Innovation and Excellence

## Teaching Associate Professor

Wendy Fisher, Computer Science, Teaching Associate Professor

## Arthur Lakes Library

Carol Smith, University Librarian

## Colorado Geological Survey

Kevin McCoy, Engineeering Geologist

# Humanitarian Engineering

## Degrees

- Master of Science in Humanitarian Engineering and Science (Thesis and Non-Thesis options).
- Graduate Certificate in Humanitarian Engineering and Science

## Program Description

The MS degrees in Humanitarian Engineering and Science (HES) are a professional MS (non-thesis) and a thesis-based MS. These degrees are targeted to recent graduates or mid-career professionals with a BS in science and engineering who are interested in careers, research opportunities, and/or acquiring skills that will help them work effectively with communities. The degrees include a core HES curriculum plus an approved track of related courses in a science or engineering discipline.

The HES graduate certificate is designed for professionals seeking to attend school part-time or students who are seeking degrees in other departments at Mines but still desire graduate training in humanitarian engineering and science. It consists of four courses.

In both the master's degrees and graduate certificate, a unique mix of social science, applied science, and engineering perspectives prepares students to apply knowledge about the earth to promote more sustainable and just uses of water, energy, and other earth resources and to understand and mitigate potential hazards.

To achieve the Master of Science (MS) degree, students may elect the Non-Thesis option, based exclusively upon coursework and a practicum, or the Thesis option. The thesis option is comprised of coursework in combination with individual research performed under the guidance of two faculty advisors and presented in a written thesis approved by the student's committee. HES students have academic advisors from both the Engineering, Design & Society Division and their disciplinary track (Environmental Engineering, Geological Engineering, or Geophysics). The thesis-based MS usually takes two years to complete, while the non-thesis MS can often be completed in one year.

For more information on program curriculum please refer to the HES website: https://humanitarian.mines.edu/mshes/.

PRIMARY CONTACT

Jessica Smith
303.384.3944
jmsmith@mines.edu

## Program Requirements

The MS degrees in *Humanitarian Engineering and Science (HES)* are a professional MS (non-thesis) and a thesis-based MS. These degrees are targeted to recent graduates or mid-career professionals with a BS in science and engineering who are interested in careers, research opportunities, and/or acquiring skills that will help them work effectively with communities. The degrees include a core HES curriculum plus an approved track of related courses in a science or engineering discipline. A unique mix of social science, applied science, and engineering perspectives prepares students to apply knowledge about the earth to promote more sustainable and just uses of water, energy, and other earth resources and to understand and mitigate potential hazards.

## Master of Science (Non-Thesis)

To obtain the 30 credits, students must satisfy the following program requirements: (1) 12 credits of required HES courses; (2) 3 credits of elective HES courses approved by Engineering, Design & Society; and (3) 15 credits of courses (500+ level) approved by the affiliated Department.

***HES Courses (15 credits):***

| | | |
|---|---|---|
| EDNS577 | ADVANCED ENGINEERING AND SUSTAINABLE COMMUNITY DEVELOPMENT | 3.0 |
| EDNS479 | COMMUNITY-BASED RESEARCH | 3.0 |
| EDNS590 | RISKS IN HUMANITARIAN ENGINEERING AND SCIENCE | 3.0 |
| EDNS580 | HUMANITARIAN ENGINEERING AND SCIENCE CAPSTONE PRACTICUM | 3.0 |
| ELECTIVES | 3 credit hours of approved HES electives from list | 3.0 |

***Approved HES Electives List:***

| | | |
|---|---|---|
| EDNS430 | CORPORATE SOCIAL RESPONSIBILITY | 3.0 |
| EDNS475 | ENGINEERING CULTURES IN THE DEVELOPING WORLD | 3.0 |
| EDNS478 | ENGINEERING AND SOCIAL JUSTICE | 3.0 |
| EDNS480 | ANTHROPOLOGY OF DEVELOPMENT | 3.0 |
| HASS425 | INTERCULTURAL COMMUNICATION | 3.0 |
| HASS525 | ENVIRONMENTAL COMMUNICATION | 3.0 |
| HASS565 | SCIENCE, TECHNOLOGY, AND SOCIETY | 3.0 |
| MNGN482 | MINE MANAGEMENT | 3.0 |
| MNGN503 | MINING TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT | 3.0 |
| MNGN510 | FUNDAMENTALS OF MINING AND MINERAL RESOURCE DEVELOPMENT | 3.0 |
| MNGN565 | MINE RISK MANAGEMENT | 3.0 |
| MNGN567 | SUSTAINABLE DEVELOPMENT AND EARTH RESOURCES | 3.0 |
| MNGN571 | ENERGY, NATURAL RESOURCES, AND SOCIETY | 3.0 |
| PEGN530 | ENVIRONMENTAL LAW AND SUSTAINABILITY | 3.0 |
| CEEN401 | LIFE CYCLE ASSESSMENT | 3.0 |
| CEEN472 | ONSITE WATER RECLAMATION AND REUSE | 3.0 |
| CEEN477 | SUSTAINABLE ENGINEERING DESIGN | 3.0 |
| CEEN479 | AIR POLLUTION | 3.0 |
| CEEN475/575 | SITE REMEDIATION ENGINEERING | 3.0 |
| CEEN556 | MINING AND THE ENVIRONMENT | 3.0 |
| CEEN570 | WATER AND WASTEWATER TREATMENT | 3.0 |
| CEEN573 | RECLAMATION OF DISTURBED LANDS | 3.0 |
| CEEN576 | POLLUTION PREVENTION: FUNDAMENTALS AND PRACTICE | 3.0 |
| CEEN580 | CHEMICAL FATE AND TRANSPORT IN THE ENVIRONMENT | 3.0 |
| CEEN581 | WATERSHED SYSTEMS MODELING | 3.0 |
| CEEN592 | ENVIRONMENTAL LAW | 3.0 |

## Disciplinary Tracks

### *Track 1: Geophysics (GPGN) (15 credits):*

Degree candidates should have an undergraduate degree in geophysics, physics, quantitative earth sciences and engineering, or equivalent coursework. In addition, candidates will need to complete necessary prerequisite courses for the graduate courses.

| | | |
|---|---|---|
| GPGN577 | HUMANITARIAN GEOSCIENCE | 3.0 |
| GPGN533 | GEOPHYSICAL DATA INTEGRATION & GEOSTATISTICS | 3.0 |
| GPGN570 | APPLICATIONS OF SATELLITE REMOTE SENSING | 3.0 |
| GPGN574 | ADVANCED HYDROGEOPHYSICS | 3.0 |
| ELECTIVES | 3 credits of approved 500-level GPGN electives | 3.0 |

#### *Approved GPGN Electives List:*

| | | |
|---|---|---|
| GPGN509 | PHYSICAL AND CHEMICAL PROPERTIES AND PROCESSES IN ROCK, SOILS, AND FLUIDS | 3.0 |
| GPGN511 | ADVANCED GRAVITY AND MAGNETIC METHODS | 3.0 |
| GPGN520 | ELECTRICAL AND ELECTROMAGNETIC EXPLORATION | 3.0 |
| GPGN530 | APPLIED GEOPHYSICS | 3.0 |
| GPGN555 | EARTHQUAKE SEISMOLOGY | 3.0 |
| GPGN561 | SEISMIC DATA PROCESSING I | 3.0 |
| GPGN605 | INVERSION THEORY | 3.0 |
| Other GPGN 500- or 600-level courses as approved by the GNGN program coordinator | | |

### *Track 2: Environmental Engineering (CEEN) (15 credits):*

A BS degree in a science or engineering discipline is required. Pre-requisites include two semesters of college calculus, one semester of college physics, two semesters of college chemistry, and one semester of college statistics.

| | | |
|---|---|---|
| **Required Courses:** | | |
| CEEN550 | PRINCIPLES OF ENVIRONMENTAL CHEMISTRY | 3.0 |
| GPGN577 | HUMANITARIAN GEOSCIENCE | 3.0 |
| CEEN580 | CHEMICAL FATE AND TRANSPORT IN THE ENVIRONMENT | 3.0 |
| **One of the Following:** | | |
| CEEN560 | MOLECULAR MICROBIAL ECOLOGY AND THE ENVIRONMENT | 3.0 |
| CEEN562 | ENVIRONMENTAL GEOMICROBIOLOGY | 3.0 |
| CEEN566 | MICROBIAL PROCESSES, ANALYSIS AND MODELING | 3.0 |
| **One of the Following:** | | |
| CEEN472 | ONSITE WATER RECLAMATION AND REUSE | 3.0 |
| CEEN570 | WATER AND WASTEWATER TREATMENT | 3.0 |

#### *Approved CEEN Electives List:*

The following courses can be substituted for required track courses if incoming students have already taken some of the required courses:

| | | |
|---|---|---|
| CEEN477 | SUSTAINABLE ENGINEERING DESIGN | 3.0 |
| CEEN479 | AIR POLLUTION | 3.0 |
| CEEN501 | LIFE CYCLE ASSESSMENT | 3.0 |
| CEEN/MNGN556 | MINING AND THE ENVIRONMENT | 3.0 |
| CEEN573 | RECLAMATION OF DISTURBED LANDS | 3.0 |
| CEEN575 | HAZARDOUS WASTE SITE REMEDIATION | 3.0 |
| CEEN576 | POLLUTION PREVENTION: FUNDAMENTALS AND PRACTICE | 3.0 |
| CEEN581 | WATERSHED SYSTEMS MODELING | 3.0 |
| CEEN592 | ENVIRONMENTAL LAW | 3.0 |
| Other CEEN 500- or 600-level courses as approved by the CEEN Program Coordinator | | |

### *Track 3: Geological Engineering (GEGN) (15 credits):*

Degree candidates should have an undergraduate degree in engineering or the equivalent coursework. In addition, candidates will need to complete necessary prerequisite courses for the graduate courses, including engineering geology, ground-water engineering, soil mechanics, and rock mechanics.

| | | |
|---|---|---|
| **Required Courses:** | | |
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| GPGN577 | HUMANITARIAN GEOSCIENCE | 3.0 |
| **Candidates must also take at least three of the following courses. The student and the instructor will work together to develop humanitarian themes in the project assignments within each course.** | | |
| GEGN563 | APPLIED NUMERICAL MODELLING FOR GEOMECHANICS | 3.0 |
| GEGN570 | CASE HISTORIES IN GEOLOGICAL ENGINEERING AND HYDROGEOLOGY | 3.0 |
| GEGN573 | GEOLOGICAL ENGINEERING SITE INVESTIGATION | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEGN580 | APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEOSCIENCES | 3.0 |
| GEGN671 | LANDSLIDES: INVESTIGATION, ANALYSIS & MITIGATION | 3.0 |
| GEGN673 | ADVANCED GEOLOGICAL ENGINEERING DESIGN | 3.0 |

## Master of Science (Thesis)

To obtain the 30 credits, students must satisfy the following program requirements: (1) 9 credits of required HES courses; (2) 3 credits of elective HES classes approved by Engineering, Design & Society; (3) 12 credits of approved Disciplinary Track classes (500+ level); and (4) 6 credits of MS thesis research on a thesis topic approved by HES faculty in the Engineering, Design, & Society Division and the affiliated disciplinary track.

#### *HES Courses (12 credits in addition to the 6 credit hour thesis):*

| | | |
|---|---|---|
| EDNS577 | ADVANCED ENGINEERING AND SUSTAINABLE COMMUNITY DEVELOPMENT | 3.0 |
| EDNS479 | COMMUNITY-BASED RESEARCH | 3.0 |

| | | |
|---|---|---|
| EDNS590 | RISKS IN HUMANITARIAN ENGINEERING AND SCIENCE | 3.0 |
| ELECTIVES | 3 credits of approved HES electives from list above | 3.0 |

## Disciplinary Tracks

### Track 1: Geophysics (GPGN) Courses and Thesis (18 credits):

| | | |
|---|---|---|
| GPGN577 | HUMANITARIAN GEOSCIENCE | 3.0 |
| GPGN533 | GEOPHYSICAL DATA INTEGRATION & GEOSTATISTICS | 3.0 |
| GPGN570 | APPLICATIONS OF SATELLITE REMOTE SENSING | 3.0 |
| GPGN574 | ADVANCED HYDROGEOPHYSICS | 3.0 |
| GPGN707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 6.0 |

### Track 2: Environmental Engineering (CEEN) Courses and Thesis (18 credits):

| | | |
|---|---|---|
| GPGN577 | HUMANITARIAN GEOSCIENCE | 3.0 |
| CEEN707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 1-15 |
| **Choose three of the following four options:** | | |
| CEEN550 | PRINCIPLES OF ENVIRONMENTAL CHEMISTRY | 3.0 |
| CEEN580 | CHEMICAL FATE AND TRANSPORT IN THE ENVIRONMENT | 3.0 |
| **One of the following:** | | |
| CEEN560 | MOLECULAR MICROBIAL ECOLOGY AND THE ENVIRONMENT | |
| CEEN562 | ENVIRONMENTAL GEOMICROBIOLOGY | |
| CEEN566 | MICROBIAL PROCESSES, ANALYSIS AND MODELING | |
| **One of the following:** | | |
| CEEN472 | ONSITE WATER RECLAMATION AND REUSE | |
| CEEN570 | WATER AND WASTEWATER TREATMENT | |

#### *Approved CEEN Electives:*

The courses listed in the Approved CEEN Electives List above can be substituted for required track courses if incoming students have already taken some of the required courses.

### Track 3: Geological Engineering Courses and Thesis (18 credits):

| | | |
|---|---|---|
| GPGN577 | HUMANITARIAN GEOSCIENCE | 3.0 |
| GEGN707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 1-15 |
| **Students must take two of the following courses:** | | |
| GEGN563 | APPLIED NUMERICAL MODELLING FOR GEOMECHANICS | 3.0 |
| GEGN570 | CASE HISTORIES IN GEOLOGICAL ENGINEERING AND HYDROGEOLOGY | 3.0 |
| GEGN573 | GEOLOGICAL ENGINEERING SITE INVESTIGATION | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEGN580 | APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEOSCIENCES | 3.0 |
| GEGN671 | LANDSLIDES: INVESTIGATION, ANALYSIS & MITIGATION | 3.0 |
| GEGN673 | ADVANCED GEOLOGICAL ENGINEERING DESIGN | 3.0 |

## Mines' Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any courses that count towards the graduate degree requirements as either "Required Coursework" or "Elective Coursework", as defined above, may be used for the purposes of double-counting at the discretion of the advisor (MS Non-Thesis) or thesis committee (MS Thesis or PhD.). These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit.

## Graduate Certificate

The HES certificate is designed for working professionals as well as graduate students who are enrolled in other degrees at Mines but wish to gain knowledge in humanitarian engineering and science. To obtain a graduate certificate, students must complete a minimum of 9 credit hours of the following courses. Students may not double-count courses from their undergraduate degrees. Students who have already taken one of the classes as undergraduates must find a suitable replacement, to be approved by the HES Director. Students are encouraged to take 12 credit hours of coursework if possible.

Required HES certificate courses (9 credits):

| | | |
|---|---|---|
| EDNS577 | ADVANCED ENGINEERING AND SUSTAINABLE COMMUNITY DEVELOPMENT | 3.0 |
| EDNS479 | COMMUNITY-BASED RESEARCH | 3.0 |
| EDNS590 | RISKS IN HUMANITARIAN ENGINEERING AND SCIENCE | 3.0 |

## Courses

**EDNS577. ADVANCED ENGINEERING AND SUSTAINABLE COMMUNITY DEVELOPMENT. 3.0 Semester Hrs.**
Analyzes the relationship between engineering and sustainable community development (SCD) from historical, political, ethical, cultural, and practical perspectives. Students will study and analyze different dimensions of sustainability, development, and "helping", and the role that engineering might play in each. Will include critical explorations of strengths and limitations of dominant methods in engineering problem solving, design and research for working in SCD. Through case-studies, students will analyze and evaluate projects in SCD and develop criteria for their evaluation. 3 hours lecture and discussion; 3 semester hours.

**EDNS580. HUMANITARIAN ENGINEERING AND SCIENCE CAPSTONE PRACTICUM. 3.0 Semester Hrs.**

(I, II, S) This course allows students to practice the concepts, theories and methods learned in HES courses with the goal of making relevant their academic training to real world problems. This practicum can be achieved through a number of possibilities approved by HES director, including supervision and/or shadowing in HES-related activities, engaging in a social enterprise where they do problem definition, impact gap analysis and layout a business canvas, and designing and carrying out a project or fieldwork of their own, etc. Prerequisite: EDNS570, EDNS479. 3 hours research; 3 semester hours.

**EDNS590. RISKS IN HUMANITARIAN ENGINEERING AND SCIENCE. 3.0 Semester Hrs.**

(I) This course provides students with opportunities learn about risk and ways of analyzing engineering and scientific projects in relation to risks, and to develop multiple mitigation steps. The students will learn tools to develop their own designs while also evaluating associated risks along multiple dimensions and searching out synergies. 3 hours lecture; 3 semester hours.

**EDNS598. SPECIAL TOPICS IN ENGINEERING DESIGN & SOCIETY. 6.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**EDNS599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**

Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree. Independent Study form must be completed and submitted to the Registrar.

**EDNS479. COMMUNITY-BASED RESEARCH. 3.0 Semester Hrs.**

Engineers and applied scientists face challenges that are profoundly socio-technical in nature, and communities are increasingly calling for greater participation in the decisions that affect them. Understanding the diverse perspectives of communities and being able to establish positive working relationships with their members is therefore crucial to the socially responsible practice of engineering and applied science. This course provides students with the conceptual and methodological tools to conduct community-based research. Students will learn ethnographic field methods and participatory research strategies, and critically assess the strengths and limitations of these through a final original research project. Prerequisite: HASS100. Co-requisite: HASS200.

# Hydrologic Science and Engineering

## Degrees Offered

- Master of Science (Hydrology), Thesis
- Master of Science (Hydrology), Non-thesis
- Doctor of Philosophy (Hydrology)

## Program Description

Hydrologic Science and Engineering (HSE) is comprised of faculty from several different Mines departments and offers interdisciplinary graduate degrees in hydrology.

The program offers programs of study in fundamental hydrologic science and applied hydrology with engineering applications. Our program encompasses groundwater hydrology, surface-water hydrology, vadose-zone hydrology, watershed hydrology, contaminant transport and fate, contaminant remediation, hydrogeophysics, and water policy/law.

HSE requires a core study of formal graduate courses for all degrees. Programs of study are interdisciplinary in nature, and coursework is obtained from multiple departments at Mines and is approved for each student by the student's advisor and thesis committee.

To achieve the Master of Science (MS) degree, students may elect the Non-Thesis option, based exclusively upon coursework and an independent study project or a designated design course, or the Thesis option. The thesis option is comprised of coursework in combination with individual laboratory, modeling and/or field research performed under the guidance of a faculty advisor and presented in a written thesis approved by the student's committee.

To achieve the Doctor of Philosophy (PhD) degree, students are expected to complete a combination of coursework and novel, original research, under the guidance of a faculty advisor and Doctoral committee, which culminates in a significant scholarly contribution to a specialized field in hydrologic sciences or engineering. Full-time enrollment is expected and leads to the greatest success, although part-time enrollment may be allowed under special circumstances. All doctoral students must complete the full-time, on-campus residency requirements (p. 16).

Currently, students will apply to the Hydrology program through the Graduate School and be assigned to the HSE participating department of the student's HSE advisor. Participating units include: Chemistry and Geochemistry, Civil & Environmental Engineering (CEE), Geology and Geological Engineering (GE), Geophysical Engineering, Humanities, Arts, and Social Sciences (HASS), Mechanical Engineering (ME), Mining Engineering (MN), and Petroleum Engineering (PE). HSE is part of the Western Regional Graduate Program (WICHE), a recognition that designates the programs as unique within the Western United States. An important benefit of this designation is that students from several western states are given the tuition status of Colorado residents. These states include Alaska, Arizona, California, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming.

For more information on program curriculum please refer to the HSE website at hydrology.mines.edu (http://hydrology.mines.edu).

## Program Requirements

**MS Non-Thesis**: 30 credit hours total, including a design course or independent study. (See a list of design courses below)

**MS Thesis**: 30 credit hours total, consisting of 24 credit hours of coursework and 6 credit hours of thesis credit. Students must also write and orally defend a research thesis.

**PhD:** 72 total credit hours, consisting of coursework (at least 36 h), and research (at least 24 h). Students must also successfully complete qualifying examinations, write and defend a dissertation proposal, write and defend a doctoral dissertation, and are expected to submit the dissertation work for publication in scholarly journals.

## Thesis & Dissertation Committee Requirements

Students must meet the general requirements listed in the graduate bulletin section *Graduate Degrees and Requirements*. In addition, the student's advisor or co-advisor must be an HSE faculty member. For MS thesis students, at least two committee members must be members of the HSE faculty. For doctoral students, at least 2 faculty on the committee must be a member of the HSE faculty. For PhD committee the required at-large member must be from a Mines department outside the student's home department, and where applicable, outside the students minor department.

## Prerequisites

- baccalaureate degree in a science or engineering discipline
- college calculus: two semesters required
- differential equations: one semester required
- college physics: one semester required
- college chemistry: two semesters required
- college statistics: one semester required
- fluid mechanics

Note that some prerequisites may be completed in the first few semesters of the graduate program if approved by the HSE Director/ Program Manager. Contact Cassie Glenn for questions - caungst@mines.edu

## Mines' Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any 400+ level courses that count towards the undergraduate degree requirements as "Elective Coursework" or any 500+ level course, may be used for the purposes of double-counting at the discretion of the graduate advisor. These courses must have been passed with a "B-" or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

## Required Curriculum

Students will work with their academic advisors and graduate thesis committees to establish plans of study that best fit their individual interests and goals. Each student will develop and submit a plan of study to their advisor during the first semester of enrollment. Doctoral students may transfer in credits from an earned MS graduate program according to requirements listed in the Graduate Degrees and Requirements (p. 37) section of the graduate bulletin, and after approval by the student's thesis committee.

## Core Curriculum

Curriculum areas of emphasis consist of core courses, and electives. Core courses cover four areas of knowledge: Groundwater, Surface Water, Chemistry, and Contaminant Fate and Transport. Students can elect to take 9 or 12 credit hours of core curriculum depending on selected option. Courses that meet core requirements include the following:

| | | |
|---|---|---|
| **Option #1 (9 credit hrs.)** | | |
| GEGN466 | GROUNDWATER ENGINEERING | 3.0 |
| GEGN582 | INTEGRATED SURFACE WATER HYDROLOGY | 3.0 |
| CEEN/GEGN587 | HYDROGEOCHEMICAL PROCESSES | 3.0 |
| **Option #2 (12 credit hrs.)** | | |
| GEGN466 | GROUNDWATER ENGINEERING | 3.0 |
| GEGN582 | INTEGRATED SURFACE WATER HYDROLOGY | 3.0 |
| CEEN550 | PRINCIPLES OF ENVIRONMENTAL CHEMISTRY | 3.0 |
| **AND Choose one of the following:** | | |
| CEEN584 | SUBSURFACE CONTAMINANT TRANSPORT | 3.0 |
| CEEN580 | CHEMICAL FATE AND TRANSPORT IN THE ENVIRONMENT | 3.0 |

Students who have completed coursework for a previous degree that satisfies one of these requirements can get core curriculum requirements waived with the appropriate Waiver Form and approval of advisor.

In addition, a fluid mechanics class is required for students to complete the HSE degree programs. If a student has previously taken a fluid mechanics course (for example as part of an undergraduate degree) then this requirement is met; if a student has not previously taken a fluid mechanics course this requirement can be satisfied by taking: GEGN/ CEEN 585 - Fluid Mechanics for Hydrology.

## Areas of Specialization

Students may choose to complete an Area of Specialization within the MS in Hydrology degrees by taking additional defined courses. These areas of specialization are: Hydrogeophysics, Hydrobiogeochemistry, and Hydrology, Policy, and Management. The Area of Specialization will appear on the transcripts of students who register for and complete the required coursework. Courses required for these Areas of Specialization are:

### *1. Hydrogeophysics:*

GPGN 574: Groundwater Geophysics

GPGN 533: Geophysical Data Integration & Geostatistics

GPGN 570: Satellite Remote Sensing

or GPGN 520: Advanced Electrical and Electromagnetic Methods

### *2. Hydrobiogeochemistry*

Students choose three of the following course with at least one from each of microbiology focused and geochemistry focused courses. Students with a Hydrobiogeochemistry Area of Specialization encouraged to enroll in CEEN550 and a separate Contaminant Fate and Transport course (CEEN580 or CEEN584) to satisfy the HSE core, leaving GEGN586 and CEEN551 as the geochemistry focused courses.

**Microbiology focus:**

CEEN 562 Environmental Geomicrobiology

CEEN 560 Molecular microbial ecology and the environment

**Geochemistry focus:**

CEEN550: Principles of Environmental Chemistry

GEGN 586: Numerical modeling of geochemical systems

CEEN551: Environmental Organic Chemistry

### *3. Hydrology, Policy, and Management*

Students wanting a Hydrology, Policy, and Management track will choose 3 of the following 4 courses.

HASS588: Global Water Politics & Policy

HASS584: U.S. Water Politics & Policy

EBGN537: Water Economics

HASS525: Environmental Communication

A grade of B- or better is required in all core classes for graduation.

## Design Courses

For Non-Thesis MS students, the following is a list of **Design Courses*** that may be completed in lieu of an Independent Study:

| | | |
|---|---|---|
| CEEN515 | HILLSLOPE HYDROLOGY AND STABILITY | 3.0 |
| CEEN581 | WATERSHED SYSTEMS MODELING | 3.0 |
| CEEN575 | HAZARDOUS WASTE SITE REMEDIATION | 3.0 |
| CEEN584 | SUBSURFACE CONTAMINANT TRANSPORT | 3.0 |
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEGN583 | MATHEMATICAL MODELING OF GROUNDWATER SYSTEMS | 3.0 |
| GEGN584 | FIELD METHODS IN HYDROLOGY | 3.0 |
| GEGN586 | NUMERICAL MODELING OF GEOCHEMICAL SYSTEMS | 3.0 |

**Elective courses** may be chosen from the approved list below or as approved by your advisor or thesis committee.

| | | |
|---|---|---|
| CEEN471 | WATER AND WASTEWATER TREATMENT SYSTEMS ANALYSIS AND DESIGN | 3.0 |
| CEEN511 | UNSATURATED SOIL MECHANICS | 3.0 |
| CEEN512 | SOIL BEHAVIOR | 3.0 |
| CEEN515 | HILLSLOPE HYDROLOGY AND STABILITY | 3.0 |
| CEEN560 | MOLECULAR MICROBIAL ECOLOGY AND THE ENVIRONMENT | 3.0 |
| CEEN562 | ENVIRONMENTAL GEOMICROBIOLOGY | 3.0 |
| CEEN570 | WATER AND WASTEWATER TREATMENT | 3.0 |
| CEEN571 | ADVANCED WATER TREATMENT ENGINEERING AND WATER REUSE | 3.0 |

| | | |
|---|---|---|
| CEEN575 | HAZARDOUS WASTE SITE REMEDIATION | 3.0 |
| CEEN581 | WATERSHED SYSTEMS MODELING | 3.0 |
| CEEN582 | MATHEMATICAL MODELING OF ENVIRONMENTAL SYSTEMS | 3.0 |
| CEEN611 | MULTIPHASE CONTAMINANT TRANSPORT | 3.0 |
| GEGN470 | GROUND-WATER ENGINEERING DESIGN | 3.0 |
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| GEGN573 | GEOLOGICAL ENGINEERING SITE INVESTIGATION | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEGN581 | ANALYTICAL HYDROLOGY | 3.0 |
| GEGN584 | FIELD METHODS IN HYDROLOGY | 3.0 |
| GEGN586 | NUMERICAL MODELING OF GEOCHEMICAL SYSTEMS | 3.0 |
| GEOL540 | ISOTOPE GEOCHEMISTRY AND GEOCHRONOLOGY | 3.0 |
| GPGN470 | APPLICATIONS OF SATELLITE REMOTE SENSING | 3.0 |
| MATH530 | STATISTICAL METHODS I | 3.0 |
| MATH531 | STATISTICAL METHODS II | 3.0 |
| MATH532 | SPATIAL STATISTICS | 3.0 |
| EBGN510 | NATURAL RESOURCE ECONOMICS | 3.0 |
| HASS588 | GLOBAL WATER POLITICS AND POLICY | 3.0 |
| GEGN585 | FLUID MECHANICS FOR HYDROLOGY | 2.0 |

## Directors

Jonathan (Josh) Sharp, HSE Director, Professor, Civil & Environmental Engineering

Alexis Sitchler, HSE Associate Director, Associate Professor Geology & Geological Engineering

## Department of Chemistry and Geochemistry

James Ranville, Professor

Bettina Voelker, Professor

## Department of Civil & Environmental Engineering

Christopher Higgins, Professor

Terri Hogue, Professor and Department Head CEE

Tissa Illangasekare, Professor and AMAX Distinguished Chair

Ning Lu, Professor

Junko Munakata Marr, Professor and Associate Department Head CEE

John McCray, Professor

Jonathan Sharp, Associate Professor

John Spear, Professor

## Department of Geology and Geological Engineering

David Benson, Professor

Reed Maxwell, Professor

Danica Roth, Assistant Professor

Paul Santi, Professor

Kamini Singha, Professor

Alexis Sitchler, Associate Professor

Wendy Zhou, Associate Professor and Graduate Dean

## Department of Geophysics

John Bradford, Professor &Vice Provost for External Initiatives and Dean of Earth Resources and Environmental Programs

Brandon Dugan, Associate Professor and Baker Hughes Chair in Petrophysics & Borehole Geophysics and Associate Department Head GP

Yaoguo Li, Professor

Matthew Siegfried, Assistant Professor

## Humanities, Arts and Social Sciences

Hussein Amery, Professor

Adrianne Kroepsch, Assistant Professor

## Department of Mechanical Engineering

Nils Tilton, Assistant Professor

## Department of Petroleum Engineering

Yu-Shu Wu, Professor

## Mining Engineering

Rennie Kaunda, Assistant Professor

## Economics & Business

Steven M. Smith, Assistant Professor

# Materials Science

## Degrees Offered

- Master of Science (Materials Science; thesis option or non-thesis option)
- Doctor of Philosophy (Materials Science)

## Program Description

The interdisciplinary graduate program in Materials Science exists to educate students, with at least a Bachelor of Science degree in engineering or science, in the diverse field of Materials Science. This diversity includes the four key foundational aspects of Materials Science – materials properties including characterization and modeling, materials structures, materials synthesis and processing and materials performance – as applied to materials of a variety of types (i.e., metals, ceramics, polymers, electronic materials and biomaterials). The Materials Science graduate program is responsible for administering MS (thesis and non-thesis) and PhD Degrees in Materials Science.

This interdisciplinary degree program coexists along side strong disciplinary programs in Chemistry, Chemical and Biochemical Engineering, Mechanical Engineering, Metallurgical and Materials Engineering, Mining, and Physics. The student's graduate committee will have final approval of the course of study.

## Fields of Research

- Advanced polymeric materials
- Alloy theory, concurrent design, theory-assisted materials engineering, and electronic structure theory
- Applications of artificial intelligence techniques to materials processing and manufacturing, neural networks for process modeling and sensor data processing, manufacturing process control
- Atomic scale characterization
- Atom Probe Tomography
- Biomaterials
- Ceramic processing, modeling of ceramic processing
- Characterization, thermal stability, and thermal degradation mechanisms of polymers
- Chemical and physical processing of materials, engineered materials, materials synthesis
- Chemical vapor deposition
- Coating materials and applications
- Computational condensed-matter physics, semiconductor alloys, first-principles phonon calculations
- Computer modeling and simulation
- Control systems engineering, artificial neural systems for senior data processing, polymer cure monitoring sensors, process monitoring and control for composites manufacturing
- Crystal and molecular structure determination by X-ray crystallography
- Electrodeposition
- Electron and ion microscopy
- Energetic materials (explosives) and processing
- Energy storage
- Experimental condensed-matter physics, thermal and electrical properties of materials, superconductivity, photovoltaics
- Fuel cell materials
- Fullerene synthesis, combustion chemistry
- Heterogeneous catalysis, reformulated and alcohol fuels, surface analysis, electrophotography
- High temperature ceramics
- Intelligent automated systems, intelligent process control, robotics, artificial neural systems
- Materials synthesis, interfaces, flocculation, fine particles
- Mathematical modeling of material processes
- Mechanical metallurgy, failure analysis, deformation of materials, advanced steel coatings
- Mechanical properties of ceramics and ceramic composites
- High entropy alloys
- Mössbauer spectroscopy, ion implantation, small-angle X-ray scattering, semiconductor defects
- Nano materials
- Non-destructive evaluation
- Non-ferrous structural alloys
- Novel separation processes: membranes, catalytic membrane reactors, biopolymer adsorbents for heavy metal remediation of ground surface water
- Numerical modeling of particulate media, thermomechanical analysis
- Optical properties of materials and interfaces
- Phase transformations and mechanisms of microstructural change
- Photovoltaic materials and device processing
- Physical metallurgy, ferrous and nonferrous alloy systems
- Physical vapor deposition, thin films, coatings
- Power electronics, plasma physics, pulsed power, plasma material processing
- Processing and characterization of electroceramics (ferro-electrics, piezoelectrics, pyroelectrics, and dielectrics)
- Semiconductor materials and device processing
- Soft materials
- Solidification and near net shape processing
- Surface physics, epitaxial growth, interfacial science, adsorption
- Thermoelectric materials
- Transport phenomena and mathematical modeling
- Weld metallurgy, materials joining processes
- Welding and joining science

## Combined Degree Option

Mines undergraduate students have the opportunity to begin work on a MS non-thesis degree while concurrently completing their Bachelor's degree at Mines.

## Dual Degree Program Option

Students have the opportunity to earn two degrees with the dual degree option. Students complete coursework to satisfy requirements for both a non-thesis MS in Materials Science from the Colorado School of Mines and a MS of Physical Chemistry and Chemical Physics from the University of Bordeaux.

## Program Requirements

Each of the three degree programs (non-thesis MS, thesis-based MS, and PhD) require the successful completion of three core courses for a total of 9 credit hours that will be applied to the degree program course requirements. Depending upon the individual student's background, waivers for these courses may be approved by the program director. In order to gain a truly interdisciplinary understanding of Materials Science, students in the program are encouraged to select elective courses from several different departments outside of their home department. Course selection should be completed in consultation with the student's advisor or program director as appropriate.

## Mines' Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Double counting **only applies towards the Master of Science Non-Thesis Option** (not a thesis MS or a PhD). Any 400+ level courses that count towards the undergraduate degree requirements as "Elective Coursework" or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a "B" or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

Listed below are the three required Materials Science core courses:

| | | |
|---|---|---|
| MLGN591 | MATERIALS THERMODYNAMICS | 3.0 |
| MLGN592 | ADVANCED MATERIALS KINETICS AND TRANSPORT | 3.0 |
| MLGN593 | BONDING, STRUCTURE, AND CRYSTALLOGRAPHY | 3.0 |
| Total Semester Hrs | | 9.0 |

## Master of Science (Thesis Option)

The Master of Science degree requires a minimum of 30.0 semester hours of acceptable coursework and thesis research credits (see table below). The student must also submit a thesis and pass the Defense of Thesis examination before the Thesis Committee.

| | | |
|---|---|---|
| MLGN591 | MATERIALS THERMODYNAMICS | 3.0 |
| MLGN592 | ADVANCED MATERIALS KINETICS AND TRANSPORT | 3.0 |
| MLGN593 | BONDING, STRUCTURE, AND CRYSTALLOGRAPHY | 3.0 |
| MLGNXXX | Materials Science Courses | 9.0 |
| MLGN707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 12.0 |
| Total Semester Hrs | | 30.0 |

## Master of Science (Non-Thesis Option with a case study)

The Master of Science degree requires a minimum of 24.0 semester hours of acceptable course work and 6.0 additional credit hours of either case study or designated design course including:

| | | |
|---|---|---|
| MLGN591 | MATERIALS THERMODYNAMICS | 3.0 |
| MLGN592 | ADVANCED MATERIALS KINETICS AND TRANSPORT | 3.0 |
| MLGN593 | BONDING, STRUCTURE, AND CRYSTALLOGRAPHY | 3.0 |
| MLGNXXX | Materials Science Courses | 15.0 |
| MLGNXXX | Case Study OR Designated Design Courses *See table below | 6.0 |
| Total Semester Hrs | | 30.0 |

### MLGN Design Courses

| | | |
|---|---|---|
| MLGN500 | PROCESSING, MICROSTRUCTURE, AND PROPERTIES OF MATERIALS | 3.0 |
| MLGN501 | STRUCTURE OF MATERIALS | 3.0 |
| MLGN503 | CHEMICAL BONDING IN MATERIALS | 3.0 |
| MLGN505 | MECHANICAL PROPERTIES OF MATERIALS | 3.0 |
| MLGN509 | SOLID STATE CHEMISTRY | 3.0 |
| MLGN510 | SURFACE CHEMISTRY | 3.0 |
| MLGN516 | PROPERTIES OF CERAMICS | 3.0 |
| MLGN535 | INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY | 3.0 |
| MLGN544 | PROCESSING OF CERAMICS | 3.0 |
| MLGN550 | STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS | 3.0 |
| MLGN561 | TRANSPORT PHENOMENA IN MATERIALS PROCESSING | 3.0 |
| MLGN569 | FUEL CELL SCIENCE AND TECHNOLOGY | 3.0 |
| MLGN583 | PRINCIPLES AND APPLICATIONS OF SURFACE ANALYSIS TECHNIQUES | 3.0 |
| MLGN5XX | Additional courses can be approved by MLGN Program Director | 3.0 |

## Doctor of Philosophy

The Doctor of Philosophy degree requires a minimum of 72.0 hours of course and research credit including:

| | | |
|---|---|---|
| MLGN591 | MATERIALS THERMODYNAMICS | 3.0 |
| MLGN592 | ADVANCED MATERIALS KINETICS AND TRANSPORT | 3.0 |
| MLGN593 | BONDING, STRUCTURE, AND CRYSTALLOGRAPHY | 3.0 |
| MLGN707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT Minimum | 24.0 |
| MLGNXXX | Materials Science Courses (minimum) | 15.0 |
| MLGNXXX | Thesis Research or Material Science Coursework | 24.0 |
| Total Semester Hrs | | 72.0 |

A minimum of 15 course credits earned at Mines is required for the PhD degree. In exceptional cases, this 15 Mines course credit hour requirement can be reduced in part or in full through the written consent of the student's advisor, program director, and thesis committee.

## PhD Qualifying Process

The following constitutes the qualifying processes by which doctoral students are admitted to candidacy in the Materials Science program.

Core Curriculum – The three required core classes must be completed in the first full academic year for all doctoral candidates. Students must obtain a grade of B- or better in each class to be eligible to take the qualifying examination at the end of the succeeding spring semester.

If not allowed to complete the qualifying examination at the end of the spring semester, students will be discouraged from the PhD program and encouraged, rather, to finish with a Masters degree

PhD Qualifying Examination – A qualifying examination is given annually at the end of the spring semester under the direction of the Materials Science Graduate Affairs Committee. All first-year Materials Science PhD students are expected to successfully complete the qualifying examination to remain in good standing in the program. The examination covers material from the core curriculum plus a standard introductory text on Materials Science, such as "Materials Science and Engineering: An Introduction", by William Callister. If a student performs below the expectations of the Materials Science faculty on the written exam, they will be asked to complete a follow-up oral examination in the summer semester. The oral examination will be based on topics deemed to be deficient in the written examination. Satisfactorily completing the oral exam will allow the student to proceed with the PhD program. Students who perform below the expectations of the Materials Science faculty on the oral exam will not be allowed to continue with the PhD program.

Upon completion of these steps and upon completion of all required coursework, candidates are admitted to candidacy.

PhD Thesis Proposal – While the proposal itself should focus on the central topic of a student's research efforts, during the proposal defense, candidates may expect to receive a wide range of questions from the Committee. This would include all manner of questions directly related to the proposal. Candidates, however, should also expect questions related to the major concept areas of Materials Science within the context of a candidate's research focus. The Committee formally reports results of the PhD proposal defense to the Materials Science Program Director using the Committee Reporting form developed by the Office of Graduate Studies.

Following successful completion of coursework and the PhD qualifying process, candidates must also submit a thesis and successfully complete the PhD Defense of Thesis examination before the PhD Thesis Committee.

## Courses

**MLGN500. PROCESSING, MICROSTRUCTURE, AND PROPERTIES OF MATERIALS. 3.0 Semester Hrs.**
(II) A summary of the important relationships between the processing, microstructure, and properties of materials. Topics include electronic structure and bonding, crystal structures, lattice defects and mass transport, glasses, phase transformation, important materials processes, and properties including: mechanical and rheological, electrical conductivity, magnetic, dielectric, optical, thermal, and chemical. In a given year, one of these topics will be given special emphasis. Another area of emphasis is phase equilibria. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MLGN501. STRUCTURE OF MATERIALS. 3.0 Semester Hrs.**
(I) Application of X-ray diffraction techniques for crystal and molecular structure determination of minerals, inorganic and organometallic compounds. Topics include the heavy atom method, data collection by moving film techniques and by diffractometers, Fourier methods, interpretation of Patterson maps, refinement methods, and direct methods. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered alternate years.

**MLGN502. SOLID STATE PHYSICS. 3.0 Semester Hrs.**
An elementary study of the properties of solids including crystalline structure and its determination, lattice vibrations, electrons in metals, and semiconductors. (Graduate students in physics may register only for PHGN440.) Prerequisite: PH320. 3 hours lecture; 3 semester hours.

**MLGN503. CHEMICAL BONDING IN MATERIALS. 3.0 Semester Hrs.**
(I) Introduction to chemical bonding theories and calculations and their applications to solids of interest to materials science. The relationship between a material's properties and the bonding of its atoms will be examined for a variety of materials. Includes an introduction to organic polymers. Computer programs will be used for calculating bonding parameters. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MLGN504. SOLID STATE THERMODYNAMICS. 3.0 Semester Hrs.**
(I) Thermodynamics applied to solid state reactions, binary and ternary phase diagrams, point, line and planar defects, interfaces, and electrochemical concepts. Prerequisites: none. 3 hours lecture; 3 semester hours.

**MLGN505. MECHANICAL PROPERTIES OF MATERIALS. 3.0 Semester Hrs.**
(I) Mechanical properties and relationships. Plastic deformation of crystalline materials. Relationships of microstructures to mechanical strength. Fracture, creep, and fatigue. Prerequisite: MTGN348. 3 hours lecture; 3 hours lab; 3/4 semester hours. *This is a 3 credit-hour graduate course in the Materials Science Program and a 4 credit-hour undergraduate-course in the MTGN program.

**MLGN506. TRANSPORT IN SOLIDS. 3.0 Semester Hrs.**
(II) Thermal and electrical conductivity. Solid state diffusion in metals and metal systems. Kinetics of metallurgical reactions in the solid state. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of even years only.).

**MLGN509. SOLID STATE CHEMISTRY. 3.0 Semester Hrs.**
(I) Dependence on properties of solids on chemical bonding and structure; principles of crystal growth, crystal imperfections, reactions and diffusion in solids, and the theory of conductors and semiconductors. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered alternate years.

**MLGN510. SURFACE CHEMISTRY. 3.0 Semester Hrs.**
Introduction to colloid systems, capillarity, surface tension and contact angle, adsorption from solution, micelles and microemulsions, the solid/gas interface, surface analytical techniques, Van Der Waal forces, electrical properties and colloid stability, some specific colloid systems (clays, foams and emulsions). Students enrolled for graduate credit in MLGN510 must complete a special project.

**MLGN511. KINETIC CONCERNS IN MATERIALS PROCESSING I. 3.0 Semester Hrs.**
(I) Introduction to the kinetics of materials processing, with emphasis on the momentum, heat and mass transport. Discussion of the basic mechanism of transport in gases, liquids and solids. Prerequisite: MTGN352, MTGN361, MATH225 or equivalent. 3 hours lecture; 3 semester hours.

**MLGN512. CERAMIC ENGINEERING. 3.0 Semester Hrs.**
(II) Application of engineering principles to nonmetallic and ceramic materials. Processing of raw materials and production of ceramic bodies, glazes, glasses, enamels, and cements. Firing processes and reactions in glass bonded as well as mechanically bonded systems. Prerequisite: MTGN348. 3 hours. lecture; 3 semester hours.

**MLGN515. ELECTRICAL PROPERTIES AND APPLICATIONS OF MATERIALS. 3.0 Semester Hrs.**
(II) Survey of the electrical properties of materials, and the applications of materials as electrical circuit components. The effects of chemistry, processing, and microstructure on the electrical properties will be discussed, along with functions, performance requirements, and testing methods of materials for each type of circuit component. The general topics covered are conductors, resistors, insulators, capacitors, energy convertors, magnetic materials, and integrated circuits. Prerequisites: PHGN200; MTGN311 or MLGN501; MTGN412/MLGN512,. 3 hours lecture; 3 semester hours.

**MLGN516. PROPERTIES OF CERAMICS. 3.0 Semester Hrs.**
(II) A survey of the properties of ceramic materials and how these properties are determined by the chemical structure (composition), crystal structure, and the microstructure of crystalline ceramics and glasses. Thermal, optical, and mechanical properties of single-phase and multi-phase ceramics, including composites, are covered. Prerequisites: PHGN200, MTGN311 or MLGN501, MTGN412. 3 semester hours: 3 hours lecture.

**MLGN517. SOLID MECHANICS OF MATERIALS. 3.0 Semester Hrs.**
This Advanced Mechanics of Materials course builds upon the learning outcomes of the pre-requisite Mechanics of Materials (Solid Mechanics) course to teach students the fundamentals of elastic deformations. Introduction to Theory of Elasticity and to Fracture Mechanics is realized through theory development, application examples, and numerical solutions. Knowledge from this course will enable students to work on variety of engineering applications in Mechanical, Materials, Aerospace, Civil and related engineering fields. Major covered topics include: vector and tensor calculus, stress and strain, stress functions, elastic constitutive equations, yield theories, numerical implementation techniques, and an introduction to applications including fracture mechanics. Prerequisite: CEEN311 (C- or better) or MEGN212 (C- or better).

**MLGN518. PHASE EQUILIBRIA IN CERAMICS SYSTEMS. 3.0 Semester Hrs.**
(II) Application of one of four component oxide diagrams to ceramic engineering problems. Emphasis on refractories and glasses and their interaction with metallic systems. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MLGN519. NON-CRYSTALLINE MATERIALS. 3.0 Semester Hrs.**
(I) An introduction to the principles of glass science and engineering and non-crystalline materials in general. Glass formation, structure, crystallization and properties will be covered, along with a survey of commercial glass compositions, manufacturing processes and applications. Prerequisites: MTGN311 or MLGN501; MLGN512/ MTGN412. 3 hours lecture; 3 semester hours.

**MLGN521. KINETIC CONCERNS IN MATERIAL PROCESSING II. 3.0 Semester Hrs.**
(I, II) Advanced course to address the kinetics of materials processing, with emphasis in those processes that promote phase and structural transformations. Processes that involve precipitation, sintering, oxidation, solgel, coating, etc., will be discussed in detail. Prerequisite: MLGN511. 3 hours lecture; 3 semester hours.

**MLGN523. APPLIED SURFACE AND SOLUTION CHEMISTRY. 3.0 Semester Hrs.**
(II) Solution and surface chemistry of importance in mineral and metallurgical operations. Pre requisite: none. 3 semester hours. (Spring of odd years only.).

**MLGN526. GEL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.**
An introduction to the science and technology of particulate and polymeric gels, emphasizing inorganic systems. Interparticle forces. Aggregation, network formation, percolation, and the gel transition. Gel structure, rheology, and mechanical properties. Application to solid-liquid separation operations (filtration, centrifugation, sedimentation) and to ceramics processing. Prerequisite: Graduate level status. 3 hours lecture; 3 semester hours. Spring of odd years only.

**MLGN530. INTRODUCTION TO POLYMER SCIENCE. 3.0 Semester Hrs.**
Chemistry and thermodynamics of polymers and polymer solutions. Reaction engineering of polymerization. Characterization techniques based on solution properties. Materials science of polymers in varying physical states. Processing operations for polymeric materials and use in separations. Prerequisite: CHGN221, MATH225, CHEN357. 3 hour lecture, 3 semester hours.

**MLGN531. POLYMER ENGINEERING AND TECHNOLOGY. 3.0 Semester Hrs.**
(II) This class provides a background in polymer fluid mechanics, polymer rheological response and polymer shape forming. The class begins with a discussion of the definition and measurement of material properties. Interrelationships among the material response functions are elucidated and relevant correlations between experimental data and material response in real flow situations are given. Processing operations for polymeric materials will then be addressed. These include the flow of polymers through circular, slit, and complex dies. Fiber spinning, film blowing, extrusion and co-extrusion will be covered as will injection molding. Graduate students are required to write a term paper and take separate examinations which are at a more advanced level. Prerequisite: CRGN307, EGGN351 or equivalent. 3 hours lecture; 3 semester hours.

**MLGN535. INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY. 3.0 Semester Hrs.**
Equivalent with
CBEN435,CBEN535,CHEN435,CHEN535,PHGN435,PHGN535,
(II) Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MLGN536. ADVANCED POLYMER SYNTHESIS. 3.0 Semester Hrs.**
(II) An advanced course in the synthesis of macromolecules. Various methods of polymerization will be discussed with an emphasis on the specifics concerning the syntheses of different classes of organic and inorganic polymers. Prerequisite: CHGN430, ChEN415, MLGN530. 3 hours lecture, 3 semester hours.

**MLGN544. PROCESSING OF CERAMICS. 3.0 Semester Hrs.**
(II) A description of the principles of ceramic processing and the relationship between processing and microstructure. Raw materials and raw material preparation, forming and fabrication, thermal processing, and finishing of ceramic materials will be covered. Principles will be illustrated by case studies on specific ceramic materials. A project to design a ceramic fabrication process is required. Field trips to local ceramic manufacturing operations are included. Prerequisites: MTGN311, MTGN331, and MTGN412/MLGN512. 3 hours lecture; 3 semester hours.

**MLGN550. STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS. 3.0 Semester Hrs.**
(I) An introduction to statistical process control, process capability analysis and experimental design techniques. Statistical process control theory and techniques will be developed and applied to control charts for variables and attributes involved in process control and evaluation. Process capability concepts will be developed and applied for the evaluation of manufacturing processes. The theory and application of designed experiments will be developed and applied for full factorial experiments, fractional factorial experiments, screening experiments, multilevel experiments and mixture experiments. Analysis of designed experiments will be carried out by graphical and statistical techniques. Computer software will be utilized for statistical process control and for the design and analysis of experiments. Prerequisite: none. 3 hours lecture, 3 semester hours.

**MLGN552. INORGANIC MATRIX COMPOSITES. 3.0 Semester Hrs.**
(I) An introduction to the processing, structure, properties and applications of metal matrix and ceramic matrix composites. Importance of structure and properties of both the matrix and the reinforcement and the types of reinforcement utilized, e.g., particulate, short fiber, continuous fiber, and laminates. Special emphasis will be placed on the development of properties such as electrical and thermal will also be examined. Prerequisite/Co-requisite: MTGN311, MTGN352, MTGN445/MLGN505. 3 hours lecture; 3 semester hours (Summer of even years only.).

**MLGN555. POLYMER AND COMPLEX FLUIDS COLLOQUIUM. 1.0 Semester Hr.**
Equivalent with CBEN555,CHGN555,
The Polymer and Complex Fluids Group at the Colorado School of Mines combines expertise in the areas of flow and field based transport, intelligent design and synthesis as well as nanomaterials and nanotechnology. A wide range of research tools employed by the group includes characterization using rheology, scattering, microscopy, microfluidics and separations, synthesis of novel macromolecules as well as theory and simulation involving molecular dynamics and Monte Carlo approaches. The course will provide a mechanism for collaboration between faculty and students in this research area by providing presentations on topics including the expertise of the group and unpublished, ongoing campus research. Prerequisites: none. 1 hour lecture; 1 semester hour. Repeatable for credit to a maximum of 3 hours.

**MLGN561. TRANSPORT PHENOMENA IN MATERIALS PROCESSING. 3.0 Semester Hrs.**
(II) Fluid flow, heat and mass transfer applied to processing of materials. Rheology of polymers, liquid metal/particles slurries, and particulate solids. Transient flow behavior of these materials in various geometries, including infiltration of liquids in porous media. Mixing and blending. Flow behavior of jets, drainage of films and particle fluidization. Surface-tension-, electromagnetic-, and bubble-driven flows. Heat -transfer behavior in porous bodies applied to sintering and solidification of composites. Simultaneous heat-and-mass-transfer applied to spray drying and drying porous bodies. Prerequisites: ChEN307 or ChEN308 or MTGN461. 3 hours lecture; 3 semester hours.

**MLGN563. POLYMER ENGINEERING: STRUCTURE, PROPERTIES AND PROCESSING. 3.0 Semester Hrs.**
(II) An introduction to the structure and properties of polymeric materials, their deformation and failure mechanisms, and the design and fabrication of polymeric end items. The molecular and crystallographic structures of polymers will be developed and related to the elastic, viscoelastic, yield and fracture properties of polymeric solids and reinforced polymer composites. Emphasis will be placed on forming techniques for end item fabrication including: extrusion, injection molding, reaction injection molding, thermoforming, and blow molding. The design of end items will be considered in relation to: materials selection, manufacturing engineering, properties, and applications. Prerequisite: MTGN311 or equivalent. 3 hours lecture; 3 semester hours.

**MLGN565. MECHANICAL PROPERTIES OF CERAMICS AND COMPOSITES. 3.0 Semester Hrs.**
(II) Mechanical properties of ceramics and ceramic-based composites; brittle fracture of solids; toughening mechanisms in composites; fatigue, high temperature mechanical behavior, including fracture, creep deformation. Prerequisites: MTGN445 or MLGN505. 3 hours lecture; 3 semester hours. (Fall of even years only.).

**MLGN569. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.**
Equivalent with MTGN569,
(II) Investigate fundamentals of fuel-call operation and electrochemistry from a chemical thermodynamics and materials science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. Prerequisites: EGGN371 or ChEN357 or MTGN351 Thermodynamics I, MATH225 Differential Equations. 3 credit hours.

**MLGN570. BIOCOMPATIBILITY OF MATERIALS. 3.0 Semester Hrs.**
(II) Introduction to the diversity of biomaterials and applications through examination of the physiologic environment in conjunction with compositional and structural requirements of tissues and organs. Appropriate domains and applications of metals, ceramics and polymers, including implants, sensors, drug delivery, laboratory automation, and tissue engineering are presented. Prerequisites: ESGN 301 or equivalent. 3 hours lecture; 3 semester hours.

**MLGN572. BIOMATERIALS. 3.0 Semester Hrs.**
Equivalent with MTGN572,
(I) A broad overview on materials science and engineering principles for biomedical applications with three main topics: 1) The fundamental properties of biomaterials; 2) The fundamental concepts in biology; 3) The interactions between biological systems with exogenous materials. Examples including surface energy and surface modification; protein adsorption; cell adhesion, spreading and migration; biomaterials implantation and acute inflammation; blood-materials interactions and thrombosis; biofilm and biomaterials-related pathological reactions. Basic principles of bio-mimetic materials synthesis and assembly will also be introduced. 3 hours lecture; 3 semester hours.

**MLGN583. PRINCIPLES AND APPLICATIONS OF SURFACE ANALYSIS TECHNIQUES. 3.0 Semester Hrs.**
(II) Instrumental techniques for the characterization of surfaces of solid materials. Applications of such techniques to polymers, corrosion, metallurgy, adhesion science, micro-electronics. Methods of analysis discussed: X-ray photoelectron spectroscopy (XPS), auger electron spectroscopy (AES), ion scattering spectroscopy (ISS), secondary ion mass spectroscopy (SIMS), Rutherford backscattering (RBS), scanning and transmission electron microscopy (SEM, TEM), energy and wavelength dispersive X-ray analysis; principles of these methods, quantification, instrumentation, sample preparation. Prerequisite: B.S. in metallurgy, chemistry, chemical engineering, physics. 3 hours lecture; 3 semester hours. This course taught in alternate even numbered years.

**MLGN591. MATERIALS THERMODYNAMICS. 3.0 Semester Hrs.**
(I) A review of the thermodynamic principles of work, energy, entropy, free energy, equilibrium, and phase transformations in single and multi-component systems. Students will apply these principles to a broad range of materials systems of current importance including solid state materials, magnetic and piezoelectric materials, alloys, chemical and electrochemical systems, soft and biological materials and nanomaterials. Prerequisites: A 300 level or higher course in thermodynamics. 3 semester hours lecture, 3 semester hours.

**MLGN592. ADVANCED MATERIALS KINETICS AND TRANSPORT. 3.0 Semester Hrs.**
(I) A broad treatment of homogenous and heterogeneous kinetic transport and reaction processes in the gas, liquid, and solid states, with a specific emphasis on heterogeneous kinetic processes involving gas/solid, liquid/solid, and solid/solid systems. Reaction rate theory, nucleation and growth, and phase transformations will be discussed. A detailed overview of mass, heat, and charge transport in condensed phases is provided including a description of fundamental transport mechanisms, the development of general transport equations, and their application to a number of example systems. Prerequisites: A 300 level or higher course in thermodynamics, introductory college chemistry, electricity and magnetism, differential equations. 3 semester hours.

**MLGN593. BONDING, STRUCTURE, AND CRYSTALLOGRAPHY. 3.0 Semester Hrs.**
(I) This course will be an overview of condensed matter structure from the atomic scale to the mesoscale. Students will gain a perspective on electronic structure as it relates to bonding, long range order as it relates to crystallography and amorphous structures, and extend these ideas to nanostructure and microstructure. Examples relating to each hierarchy of structure will be stressed, especially as they relate to reactivity, mechanical properties, and electronic and optical properties. Prerequisites: A 300 level or higher course in thermodynamics. 3 semester hours.

**MLGN597. CASE STUDY - MATERIALS SCIENCE. 0.5-6 Semester Hr.**
Individual research or special problem projects supervised by a faculty member.

**MLGN598. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**MLGN599. CASE STUDY MATERIALS SCIENCE. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree. Prerequisite: Independent Study form must be completed and submitted to the Registrar.

**MLGN607. CONDENSED MATTER. 3.0 Semester Hrs.**
(I) Principles and applications of the quantum theory of electronic in solids: structure and symmetry, electron states and excitations in metals; transport properties. Prerequisite: PHGN520 and PHGN440/MLGN502. 3 hours lecture; 3 semester hours.

**MLGN625. MOLECULAR SIMULATION METHODS. 3.0 Semester Hrs.**
(I Even Years), Principles and practice of modern computer simulation techniques used to understand solids, liquids, and gases. Review of the statistical foundation of thermodynamics followed by in-depth discussion of Monte Carlo and Molecular Dynamics techniques. Discussion of intermolecular potentials, extended ensembles, and mathematical algorithms used in molecular simulations. Prerequisites: graduate level thermodynamics (required), statistical mechanics (recommended). 3 semester hours.

**MLGN634. ADVANCED TOPICS IN THERMODYNAMICS. 3.0 Semester Hrs.**
Advanced study of thermodynamic theory and application of thermodynamic principles. Possible topics include stability, critical phenomena, chemical thermodynamics, thermodynamics of polymer solutions and thermodynamics of aqueous and ionic solutions. Prerequisite: none. 1 to 3 semester hours.

**MLGN635. POLYMER REACTION ENGINEERING. 3.0 Semester Hrs.**
This class is aimed at engineers with a firm technical background who wish to apply that background to polymerization production techniques. The class begins with a review of the fundamental concepts of reaction engineering, introduces the needed terminology and describes different reactor types. The applied kinetic models relevant to polymerization reaction engineering are then developed. Next, mixing effects are introduced; goodness of mixing and effects on reactor performance are discussed. Thermal effects are then introduced and the subjects of thermal runaway, thermal instabilities, and multiple steady states are included. Reactive processing, change in viscosity with the extent of reaction and continuous drag flow reactors are described. Polymer de-volatilization constitutes the final subject of the class. Prerequisites: CRGN518 or equivalent. 3 hours lecture; 3 semester hours.

**MLGN648. CONDENSED MATTER II. 3.0 Semester Hrs.**
(II) Principles and applications of the quantum theory of electronic and phonons in solids; phonon states in solids; transport properties; electron states and excitation in semiconductors and insulators; magnetism; superconductivity. Prerequisite: PHGN640/MLGN607. 3 hours lecture; 3 semester hours.

**MLGN673. STRUCTURE AND PROPERTIES OF POLYMERS. 3.0 Semester Hrs.**
This course will provide an understanding of structure- properties relations in polymeric materials. The topics include: phase separation, amorphous structures, crystalline structures, liquid crystals, glass-rubber transition behavior, rubber elasticity, viscoelasticity, mechanical properties of polymers, polymer forming processes, and electrical properties of polymers. Prerequisite: MLGN563. 3 hours lecture; 3 semester hours.

**MLGN696. VAPOR DEPOSITION PROCESSES. 3.0 Semester Hrs.**
(II) Introduction to the fundamental physics and chemistry underlying the control of vapor deposition processes for the deposition of thin films for a variety of applications, e.g.,corrosion/oxidation resistance, decorative coatings, electronic and magnetic thin films. Emphasis on the vapor deposition processes and the control of process variables rather than the structure and properties of the thin films. Prerequisites: MTGN351, MTGN461, or equivalent courses. 3 hours lecture; 3 semester hours.

**MLGN698. SPECIAL TOPICS. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**MLGN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**MLGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

## Professors

Sumit Agarwal, Department of Chemical Engineering

John R. Berger, Department of Mechanical Engineering, Department Head of Mechanical Engineering

Cristian Ciobanu, Department of Mechanical Engineering

Mark Eberhart, Department of Chemistry

Kip Findley, Department of Metallurgical and Materials Engineering

Thomas Gennett, Department of Chemistry, Department Head of Chemistry

Michael J. Kaufman, Department of Metallurgical and Materials Engineering, Vice Provost, Graduate Initiatives and Dean of Materials and Energy Programs

Daniel M. Knauss, Department of Chemistry

Ryan P. O'Hayre, Department of Metallurgical and Materials Engineering

Ivar E. Reimanis, Department of Metallurgical and Materials Engineering, Herman F. Coors Distinguished Professor of Ceramic Engineering

Ryan Richards, Department of Chemistry

Angus Rockett, Department of Metallurgical and Materials Engineering, Department Head of Metallurgical and Materials Engineering

Sridhar Seetharaman, Department of Metallurgical and Materials Engineering

John Speer, Department of Metallurgical and Materials Engineering, American Bureau of Shipping Endowed Chair in Metallurgical and Materials Engineering

Timothy Strathmann, Department of Civil and Environmental Engineering

Brian Thomas, Department of Mechanical Engineering

Colin Wolden , Department of Chemical Engineering, Weaver Distinguished Professor

Kim Williams, Department of Chemistry

David T. Wu, Department of Chemistry

## Associate Professors

Geoff Brennecka, Department of Metallurgical and Materials Engineering, Assistant Director of Materials Science

Amy Clarke, Department of Metallurgical and Materials Engineering

Emmanuel De Moor, Department of Metallurgical and Materials Engineering

Brian P. Gorman, Department of Metallurgical and Materials Engineering

Jeff King, Department of Metallurgical and Materials Engineering

Timothy R. Ohno, Department of Physics

Corrine E. Packard, Department of Metallurgical and Materials Engineering

Alan Sellinger, Department of Chemistry

Aaron Stebner, Department of Mechanical Engineering

Neal Sullivan, Department of Mechanical Engineering

Eric Toberer, Department of Physics, Director of Materials Science

Brian Trewyn, Department of Chemistry

Ning Wu, Department of Chemical and Biological Engineering

Mohsen Asle Zaeem, Department of Mechanical Engineering

## Assistant Professors

Kester Clarke, Department of Metallurgical and Materials Engineering

Owen Hildreth, Department of Mechanical Engineering

Svitlana Pylypenko, Department of Chemistry

Vladan Stevanovic, Department of Metallurgical and Materials Engineering

Garritt Tucker, Department of Mechanical Engineering

Shubham Vyas, Department of Chemistry

Zhenzhen Yu, Department of Metallurgical and Materials Engineering

Jeramy Zimmerman, Department of Physics

## Professors Emeriti

Thomas E. Furtak, Department of Physics

Stephen Liu, Department of Metallurgical and Materials Engineering

Brajendra Mishra, Department of Metallurgical and Materials Engineering

P. Craig Taylor, Department of Physics

Steven Thompson, Department of Metallurgical and Materials Engineering

Chester J. Van Tyne, Department of Metallurgical and Materials Engineering

J. Douglas Way, Department of Chemical and Biological Engineering

## Teaching Professor

Gerald Bourne, Department of Metallurgical and Materials Engineering

## Research Professors

Richard K. Ahrenkiel, Department of Metallurgical and Materials Engineering

William (Grover) Coors, Department of Metallurgical and Materials Engineering

Terry Lowe, Department of Metallurgical and Materials Engineering

Paul Queneau, Department of Metallurgical and Materials Engineering

Erik Spiller, Department of Metallurgical and Materials Engineering

Jianhua Tong, Department of Metallurgical and Materials Engineering

Edgar Vidal, Department of Metallurgical and Materials Engineering

James Williams, Department of Metallurgical and Materials Engineering

## Research Associate Professors

Robert Cryderman, Department of Metallurgical and Materials Engineering

Conrad O'Kelley, Department of Metallurgical and Materials Engineering

Vilem Petr, Department of Mining

Zhigang Wu, Department of Physics

## Research Assistant Professors

David Diercks, Department of Metallurgical and Materials Engineering

Michael Sanders, Department of Metallurgical and Materials Engineering

Judith (Gomez) Vidal, Department of Metallurgical and Materials Engineering

Andriy Zakuyatev, Department of Metallurgical and Materials Engineering

## Research Associates

Carole Graas, Department of Metallurgical and Materials Engineering

Gary Zito, Department of Metallurgical and Materials Engineering

# Nuclear Engineering

## Degrees Offered

- Master of Engineering (Nuclear Engineering)
- Master of Science (Nuclear Engineering)
- Doctor of Philosophy (Nuclear Engineering)

## Program Description

The Nuclear Science and Engineering program at the Colorado School of Mines is interdisciplinary in nature and draws contributions from departments across the university. While delivering a traditional Nuclear Engineering course core, the School of Mines program in Nuclear Science and Engineering emphasizes the nuclear fuel life cycle. Faculty bring to the program expertise in all aspects of the nuclear fuel life cycle; fuel exploration and processing, nuclear power systems production, design and operation, fuel recycling, storage and waste remediation, radiation detection and radiation damage as well as the policy issues surrounding each of these activities. Related research is conducted through the Nuclear Science and Engineering Center.

Students in all three Nuclear Engineering degrees are exposed to a broad systems overview of the complete nuclear fuel cycle as well as obtaining detailed expertise in a particular component of the cycle. Breadth is assured by requiring all students to complete a rigorous set of core courses. The core consists of a 13 credit-hour course sequence. The remainder of the course and research work is obtained from the multiple participating departments, as approved for each student by the student's advisor and the student's thesis committee (as appropriate).

The Master of Engineering degree is a non-thesis graduate degree intended to supplement the student's undergraduate degree by providing the core knowledge needed to prepare the student to pursue a career in the nuclear energy field. The Master of Science and Doctor of Philosophy degrees are thesis-based degrees that emphasize research.

In addition, students majoring in allied fields may complete a minor degree through the Nuclear Science and Engineering Program, consisting of 12 credit hours of coursework. The Nuclear Science and Engineering Minor programs are designed to allow students in allied fields to acquire and then indicate, in a formal way, specialization in a nuclear-related area of expertise.

## Program Requirements

The Nuclear Science and Engineering Program offers programs of study leading to three graduate degrees:

## Master of Engineering (ME)

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|---|---|
| Core courses | 13.0 |
| Elective core courses | 12.0 |
| Additional elective courses | 3.0 |
| Nuclear Science and Engineering Seminar | 2.0 |
| Total Semester Hrs | 30.0 |

## Master of Science (MS)

| | |
|---|---|
| Core courses | 13.0 |
| Elective core courses | 6.0 |
| Nuclear Science and Engineering Seminar | 2.0 |
| Graduate research (minimum) | 12.0 |
| Graduate research or elective courses | 3.0 |
| Total Semester Hrs | 36.0 |

MS students must complete and defend a research thesis in accordance with this Graduate catalog and the Nuclear Science and Engineering Thesis Procedures (https://nuclear.mines.edu/graduate-programs/). The student must complete the preparation and defense of a Thesis Proposal as described by the Nuclear Science and Engineering Proposal Procedures (https://nuclear.mines.edu/graduate-programs/) at least one semester before the student defends his or her MS thesis.

## Doctor of Philosophy (PhD)

| | |
|---|---|
| Core courses | 13.0 |
| Elective core courses | 12.0 |
| Additional elective courses | 3.0 |
| Nuclear Science and Engineering Seminar | 4.0 |
| Graduate research (minimum) | 24.0 |
| Graduate research or elective courses | 16.0 |
| Total Semester Hrs | 72.0 |

PhD students must successfully complete the program's quality control process.

The PhD quality control process includes the following:

- Prior to admission to candidacy, the student must complete all of the Nuclear Engineering required core and elective core classes;
- Prior to admission to candidacy, the student must pass a qualifying examination in accordance with the Nuclear Science and Engineering Qualifying Exam Procedures (https://nuclear.mines.edu/graduate-programs/);
- A PhD thesis proposal must be presented to, and accepted by, the student's thesis committee in accordance with the Nuclear Science and Engineering Proposal Procedures (https://nuclear.mines.edu/graduate-programs/); and
- The student must complete and defend a PhD thesis in accordance with this Graduate catalog and the Nuclear Science and Engineering Thesis Procedures (https://nuclear.mines.edu/graduate-programs/).

## Thesis Committee Requirements

The student's thesis committee must meet the general requirements listed in the Graduate Bulletin section on Graduate Degrees and Requirements (p. 37). In addition, the student's advisor or co-advisor must be an active faculty member of Mines Nuclear Science and Engineering Program. For MS students, at least two, and for PhD students, at least three, committee members must be faculty members of the Nuclear Science and Engineering Program and must come from at least two different departments. At least one member of the PhD committee must be a faculty member from outside the Nuclear Science and Engineering Program.

## Required Curriculum

In order to be admitted to the Nuclear Science and Engineering Graduate Degree Program, students must meet the following minimum requirements:

- baccalaureate degree in a science or engineering discipline from an accredited program
- mathematics coursework up to and including differential equations

- coursework in thermodynamics
- ENGY498, Introduction to Nuclear Engineering (or equivalent).

Students who do not meet these minimum requirements may be admitted with specified coursework to be completed in the first semesters of the graduate program. These introductory courses will be selected in consultation with the student's graduate advisor.

All degree offerings within the Nuclear Science and Engineering program are based on a set of required and elective core courses. The required core classes are:

| | | |
|---|---|---|
| NUGN510 | INTRODUCTION TO NUCLEAR REACTOR PHYSICS | 3.0 |
| NUGN520 | INTRODUCTION TO NUCLEAR REACTOR THERMAL-HYDRAULICS | 3.0 |
| NUGN580 | NUCLEAR REACTOR LABORATORY (taught in collaboration with the USGS) | 3.0 |
| NUGN585<br>& NUGN586 | NUCLEAR REACTOR DESIGN I<br>and NUCLEAR REACTOR DESIGN II | 4.0 |
| Total Semester Hrs | | 13.0 |

Additionally, students pursuing a Nuclear Engineering graduate degree must take a certain number of courses from the elective core (four for a ME, two for a MS and three for a PhD). The core electives consist of the following:

| | | |
|---|---|---|
| MTGN593 | NUCLEAR MATERIALS SCIENCE AND ENGINEERING | 3.0 |
| PHGN504 | RADIATION DETECTION AND MEASUREMENT | 3.0 |
| CHGN511 | APPLIED RADIOCHEMISTRY | 3.0 |
| MEGN592 | RISK AND RELIABILITY ENGINEERING ANALYSIS AND DESIGN | 3.0 |
| NUGN506 | NUCLEAR FUEL CYCLE | 3.0 |
| NUGN590 | COMPUTATIONAL REACTOR PHYSICS | 3.0 |

Additionally, a 400- or 500-level Nuclear Physics class counts towards the credit hours required to fulfill core elective requirements. This is optional for Masters degrees but required for a PhD degree.

Students will select additional coursework in consultation with their graduate advisor and their thesis committee (where applicable). Through these additional courses, students gain breadth and depth in their knowledge the Nuclear Engineering industry.

Students seeking MS and PhD degrees are required to complete the minimum research credit hour requirements ultimately leading to the completion and defense of a thesis. Research is conducted under the direction of a member of Mines Nuclear Science and Engineering faculty and could be tied to a research opportunity provided by industry partners.

## Graduate Seminar

Full-time graduate students in the Nuclear Science and Engineering Program are expected to maintain continuous enrollment in Nuclear Science and Engineering Seminar. Students who are concurrently enrolled in a different degree program that also requires seminar attendance may have this requirement waived at the discretion of the Program Director.

## Nuclear Engineering Combined Degree Program Option

Mines undergraduate students have the opportunity to begin work on a ME or MS degree in Nuclear Engineering while completing their Bachelor's degree. The Nuclear Engineering Combined Degree Program provides the vehicle for students to use up to 6 credit hours of undergraduate coursework as part of their Nuclear Engineering Graduate Degree curriculum, as well as the opportunity to take additional graduate courses while completing their undergraduate degree. Students in the Nuclear Engineering Combined Degree Program are expected to apply for admission to the graduate program by the beginning of their Senior Year. For more information please contact the Nuclear Science and Engineering Program Director.

## Minor Degree Programs

Students majoring in allied fields may choose to complete minor degree programs through the Nuclear Science and Engineering Program indicating specialization in a nuclear-related area of expertise. Minor programs require completion of 9 credit hours of approved coursework (Masters degree), or 12 credit hours of approved coursework (Ph.D). Existing minors and their requirements are as follows, with the first three courses listed being required for a Masters degree, and the last being an additional requirement for a Ph.D. degree:

## Nuclear Engineering

| | | |
|---|---|---|
| NUGN510 | INTRODUCTION TO NUCLEAR REACTOR PHYSICS | 3.0 |
| NUGN520 | INTRODUCTION TO NUCLEAR REACTOR THERMAL-HYDRAULICS | 3.0 |
| NUGN580 | NUCLEAR REACTOR LABORATORY | 3.0 |
| MTGN598 | SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING (Nuclear Materials Politics and Public Policy) | 3.0 |
| Total Semester Hrs | | 12.0 |

## Nuclear Materials Processing

| | | |
|---|---|---|
| NUGN510 | INTRODUCTION TO NUCLEAR REACTOR PHYSICS | 3.0 |
| MTGN593 | NUCLEAR MATERIALS SCIENCE AND ENGINEERING | 3.0 |
| MTGN591 | PHYSICAL PHENOMENA OF COATING PROCESSES | 3.0 |
| CHGN511 | APPLIED RADIOCHEMISTRY | 3.0 |
| or MTGN598 | SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING | |
| Total Semester Hrs | | 12.0 |

## Nuclear Detection

| | | |
|---|---|---|
| PHGN422 | NUCLEAR PHYSICS | 3.0 |
| NUGN510 | INTRODUCTION TO NUCLEAR REACTOR PHYSICS | 3.0 |
| PHGN504 | RADIATION DETECTION AND MEASUREMENT | 3.0 |
| NUGN580 | NUCLEAR REACTOR LABORATORY | 3.0 |
| Total Semester Hrs | | 12.0 |

## Courses

**NUGN505. NUCLEAR SCIENCE AND ENGINEERING SEMINAR. 1.0 Semester Hr.**

(I, II) The Nuclear Science and Engineering Seminar provides a forum for Nuclear Engineering graduate students to present their research projects, participate in seminars given by Nuclear Science and Engineering professionals, and develop an enhanced understanding of the breadth of the nuclear engineering discipline. Prerequsite: gradaute standing. 1 hour seminar; 1 semester hour. Repeatable; maximum 2 hours granted towards M.S./M.E. Degree Requirements and 4 hours maximum granted towards Ph.D. Requirements.

**NUGN506. NUCLEAR FUEL CYCLE. 3.0 Semester Hrs.**

(I) An introduction to nuclear energy emphasizing the science, engineering, and policies underlying the systems and processes involved in energy production by nuclear fission. Students will acquire a broad understanding of nuclear energy systems framed in the context of the fuel used to power nuclear reactors. 3 hours lecture; 3 semester hours.

**NUGN510. INTRODUCTION TO NUCLEAR REACTOR PHYSICS. 3.0 Semester Hrs.**

Bridges the gap between courses in fundamental nuclear physics and the neutronic design and analysis of nuclear reactors. Review of neutron energetics and reactions; nuclear cross sections; neutron induced fission; neutron life cycle, multiplication, and criticality; nuclear reactor kinetics and control; the diffusion approximation for neutron transport; simple reactor geometries and compositions; modeling and simulation of reactors. Prerequisite: ENGY498 or equivalent.

**NUGN520. INTRODUCTION TO NUCLEAR REACTOR THERMAL-HYDRAULICS. 3.0 Semester Hrs.**

Bridges the gap between fundamental courses in thermodynamics, fluid flow, and heat transer and the thermal-hydraulic design and analysis of nuclear reactors. Provides a comprehensive introduction to the thermal-hydraulics of each of the major classes of nuclear reactors. Introduces the major thermal-hydraulic computational tools, passively safe reactor design, thermal-hydraulic transient analysis, and severe nuclear reactor accident analysis. Prerequisite: ENGY498 or equivalent.

**NUGN535. INTRODUCTION TO HEALTH PHYSICS. 3.0 Semester Hrs.**

(I) Health physics evaluates effects of ionizing radiation on biological systems for the safe use of radiation and control of potential health hazards. The core concept is dosimetry, which relates the radiation absorbed externally and internally to a quantitative estimate of health effects. Other areas in health physics such as protection standards, regulations, and radiation diagnosis and therapy are all constructed on dosimetric methods.

**NUGN580. NUCLEAR REACTOR LABORATORY. 3.0 Semester Hrs.**

(I) Provides hands-on experience with a number of nuclear reactor operations topics. Reactor power calibration; gamma spectroscopy; neutron activation analysis; reactor flux and power profiles; reactor criticality; control rod worth; xenon transients and burnout; reactor pulsing. Taught at the USGS TRIGA reactor. Prerequisite: NUGN510. 3 hours laboratory; 3 semester hours.

**NUGN585. NUCLEAR REACTOR DESIGN I. 2.0 Semester Hrs.**

Provides a basic understanding of the nuclear reactor design process, including: key features of nuclear reactors; nuclear reactor design principles; identification of design drivers; neutronic and thermal-hydraulic design of nuclear reactors; reactor safety considerations; relevant nuclear engineering computer codes. Prerequisite: NUGN510, NUGN520.

**NUGN586. NUCLEAR REACTOR DESIGN II. 2.0 Semester Hrs.**

(II) Builds on the design experience obtained in NUGN586 to provide an in-depth understanding of the nuclear reactor design process. Prerequisites: NUGN585 (taken in the same academic year). 2 hours lecture; 2 semester hours.

**NUGN590. COMPUTATIONAL REACTOR PHYSICS. 3.0 Semester Hrs.**

(I) This course will provide an introduction to computational nuclear reactor physics. Students will understand the physics driving neutron cross sections and how they determined, and how neutron transport calculations are completed using Monte Carlo and finite difference methods. Students will learn how to write modular code using professional software engineering practices, and will have an introduction to the Serpent and MCNP family of transport codes. 3 hours lecture; 3 semester hours.

**NUGN598. SPECIAL TOPICS. 6.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**NUGN599. INDEPENDENT STUDY IN NUCLEAR ENGINEERING. 0.5-6 Semester Hr.**

(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**NUGN698. SPECIAL TOPICS. 6.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**NUGN699. INDEPENDENT STUDY IN NUCLEAR ENGINEERING. 0.5-6 Semester Hr.**

(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**NUGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**

(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

## Program Director

Mark Jensen, Jerry and Tina Grandey University Chair in Nuclear Science and Engineering, Department of Chemistry

## Department of Chemistry

Jenifer Braley, Associate Professor

Mark Jensen, Professor and Jerry and Tina Grandey University Chair in Nuclear Science and Engineering

## Department of Civil and Environmental Engineering

Linda Figueroa, Professor, Nuclear Science and Engineering Center Management Team Co-Chair

## Department of Mechanical Engineering

Mark Deinert, Associate Professor

Andrew Osborne, Assistant Professor

## Department of Metallurgical and Materials Engineering

Kip Findley, Associate Professor

Jeffrey King, Associate Professor, Nuclear Science and Engineering Center Management Team Chair

Ivar Reimanis, Professor and Herman F. Coors Distinguished Professor of Ceramic Engineering

Haitao Dong, Radiation Safety Officer

## Department of Physics

Uwe Greife, Professor

Frederic Sarazin, Professor

Zeev Shayer, Research Professor

## Division of Economics and Business

Roderick Eggert, Professor

# Operations Research with Engineering

## Degrees Offered

- Master of Science in Operations Research with Engineering (Non-Thesis)
- Doctor of Philosophy in Operations Research with Engineering

## Program Description

Operations Research (OR) involves mathematically modeling physical systems (both naturally occurring and man-made) with a view to determining a course of action for the system to either improve or optimize its functionality. Examples of such systems include, but are not limited to, manufacturing systems, chemical processes, socio-economic systems, mechanical systems (e.g., those that produce energy), and mining systems.

## Program Requirements

## Master of Science in Operations Research with Engineering (Non-Thesis)

| | |
|---|---|
| Core Courses | 18.0 |
| ORWE courses not taken as core courses | 12.0 |
| Total | 30.0 |

All Masters students are required to take a set of core courses (18 hours) that provides basic tools for the more advanced and specialized courses in the program as specified below.

| | | |
|---|---|---|
| MATH530 | STATISTICAL METHODS I | 3.0 |
| MATH531 | STATISTICAL METHODS II | 3.0 |
| ORWE586 | LINEAR OPTIMIZATION | 3.0 |
| or ORWE585 | NETWORK MODELS | |
| MATH438/538 | STOCHASTIC MODELS Course may be substituted with Math 4XX Computational Linear Albebra | 3.0 |
| ORWE587 | NONLINEAR OPTIMIZATION | 3.0 |
| or ORWE588 | INTEGER OPTIMIZATION | |
| MEGN502 | ADVANCED ENGINEERING ANALYSIS | 3.0 |
| or CSCI406 | ALGORITHMS | |
| or CEEN405 | NUMERICAL METHODS FOR ENGINEERS | |
| or CEEN505 | NUMERICAL METHODS FOR ENGINEERS | |

The remaining 12 hours of coursework can be completed with any ORWE-labeled course not taken as core. Or, specialty tracks can be added in areas, for example, including: (i) operations research methodology; (ii) systems engineering; (iii) computer science; (iv) finance and economics; and (v) an existing engineering discipline that is reflected in a department name such as electrical, civil, environmental, or mining engineering.

Students who do not wish to specialize in a track mentioned in the table below and do not wish to complete 12 additional hours of ORWE-labeled coursework can "mix and match" from the ORwE coursework and coursework mentioned in the tables below in consultation with and approval from their academic advisers.

Examples of specialty tracks from various departments across campus are given below:

### Energy Systems within Mechanical Engineering Track (12 hours from the course list below)

| | | |
|---|---|---|
| MEGN461 | THERMODYNAMICS II | 3.0 |
| MEGN567 | HVAC AND BUILDING ENERGY SYSTEMS | 3.0 |
| MEGN583/ AMFG501 | ADDITIVE MANUFACTURING | 3.0 |
| MEGN570 | ELECTROCHEMICAL SYSTEMS ENGINEERING | 3.0 |
| MEGN560 | DESIGN AND SIMULATION OF THERMAL SYSTEMS | 3.0 |

### Additive Manufacturing Track (12 hours from the course list below)*

*Subject to approval by graduate council

| | | |
|---|---|---|
| AMFG511 | DATA DRIVEN ADVANCED MANUFACTURING | 3.0 |
| MEGN583/ AMFG501 | ADDITIVE MANUFACTURING | 3.0 |
| AMFG531 | MATERIALS FOR ADDITIVE MANUFACTURING | 3.0 |
| AMFG421/521 | DESIGN FOR ADDITIVE MANUFACTURING | 3.0 |

### Applied Mathematics and Statistics Track (12 hours from the course list below)

| | | |
|---|---|---|
| MATH500 | LINEAR VECTOR SPACES | 3.0 |
| MATH532 | SPATIAL STATISTICS | 3.0 |
| MATH536 | ADVANCED STATISTICAL MODELING | 3.0 |
| MATH537/538 | MULTIVARIATE ANALYSIS | 3.0 |
| MATH438/538 | STOCHASTIC MODELS | 3.0 |
| MATH551 | COMPUTATIONAL LINEAR ALGEBRA | 3.0 |
| EENG511 | CONVEX OPTIMIZATION AND ITS ENGINEERING APPLICATIONS | 3.0 |

### Economics Track (12 hours from the course list below)

| | | |
|---|---|---|
| EBGN509 | MATHEMATICAL ECONOMICS | 3.0 |
| EBGN510 | NATURAL RESOURCE ECONOMICS | 3.0 |
| EBGN530 | ECONOMICS OF INTERNATIONAL ENERGY MARKETS | 3.0 |
| EBGN535 | ECONOMICS OF METAL INDUSTRIES AND MARKETS | 3.0 |
| EBGN590 | ECONOMETRICS I | 3.0 |
| EBGN645 | COMPUTATIONAL ECONOMICS | 3.0 |
| CSCI555 | GAME THEORY AND NETWORKS | 3.0 |

### Business Track (12 hours from the course list below)

| | | |
|---|---|---|
| ORWE559 | SUPPLY CHAIN MANAGEMENT | 3.0 |
| EBGN560 | DECISION ANALYTICS | 3.0 |
| EBGN571 | MARKETING ANALYTICS | 3.0 |
| EBGN562 | STRATEGIC DECISION MAKING | 3.0 |

## Computer Science Track (12 hours from the course list below)

| | | |
|---|---|---|
| CSCI542 | SIMULATION | 3.0 |
| CSCI562 | APPLIED ALGORITHMS AND DATA STRUCTURES | 3.0 |
| CSCI571 | ARTIFICIAL INTELLIGENCE | 3.0 |
| CSCI575 | MACHINE LEARNING | 3.0 |
| CSCI555 | GAME THEORY AND NETWORKS | 3.0 |

## Civil Engineering - Geotechnics Track (12 hours from the course list below)

| | | |
|---|---|---|
| CEEN506 | FINITE ELEMENT METHODS FOR ENGINEERS | 3.0 |
| CEEN5XX | RISK ASSESSMENT IN GEOTECHNICAL ENGINEERING | 3.0 |
| CEEN510 | ADVANCED SOIL MECHANICS | 3.0 |
| CEEN511 | UNSATURATED SOIL MECHANICS | 3.0 |
| CEEN512 | SOIL BEHAVIOR | 3.0 |
| CEEN515 | HILLSLOPE HYDROLOGY AND STABILITY | 3.0 |

## Civil Engineering-Structures Track (12 hours from the course list below)

| | | |
|---|---|---|
| CEEN506 | FINITE ELEMENT METHODS FOR ENGINEERS | 3.0 |
| CEEN530 | ADVANCED STRUCTURAL ANALYSIS | 3.0 |
| CEEN531 | STRUCTURAL DYNAMICS | 3.0 |
| CEEN533 | MATRIX STRUCTURAL ANALYSIS | 3.0 |
| CEEN543 | CONCRETE BRIDGE DESIGN BASED ON THE AASHTO LRFD SPECIFICATIONS | 3.0 |
| CEEN545 | STEEL BRIDGE DESIGN | 3.0 |

## Nuclear Engineering Track (12 hours from the course list below)

| | | |
|---|---|---|
| NUGN506 | NUCLEAR FUEL CYCLE | 3.0 |
| NUGN510 | INTRODUCTION TO NUCLEAR REACTOR PHYSICS | 3.0 |
| NUGN520 | INTRODUCTION TO NUCLEAR REACTOR THERMAL-HYDRAULICS | 3.0 |
| NUGN580 | NUCLEAR REACTOR LABORATORY | 3.0 |
| NUGN590 | COMPUTATIONAL REACTOR PHYSICS | 3.0 |
| NUGN585/586 | NUCLEAR REACTOR DESIGN I | 2.0 |

## Electrical Engineering-Antennas and Wireless Communications Track (12 hours from the course list below)

| | | |
|---|---|---|
| EENG525 | ANTENNAS | 3.0 |
| EENG527 | WIRELESS COMMUNICATIONS | 3.0 |
| EENG530 | PASSIVE RF & MICROWAVE DEVICES | 3.0 |
| EENG526 | ADVANCED ELECTROMAGNETICS | 3.0 |
| EENG528 | COMPUTATIONAL ELECTROMAGNETICS | 3.0 |

## Electrical Engineering-Energy Systems and Power Electronics Track (12 hours from the course list below)

| | | |
|---|---|---|
| EENG570 | ADVANCED HIGH POWER ELECTRONICS | 3.0 |
| EENG580 | POWER DISTRIBUTION SYSTEMS ENGINEERING | 3.0 |
| EENG581 | POWER SYSTEM OPERATION AND MANAGEMENT | 3.0 |
| EENG583 | ADVANCED ELECTRICAL MACHINE DYNAMICS | 3.0 |

## Electrical Engineering-Information and Systems Sciences Track (12 hours from the course list below)

| | | |
|---|---|---|
| EENG509 | SPARSE SIGNAL PROCESSING | 3.0 |
| EENG511 | CONVEX OPTIMIZATION AND ITS ENGINEERING APPLICATIONS | 3.0 |
| EENG515 | MATHEMATICAL METHODS FOR SIGNALS AND SYSTEMS | 3.0 |
| EENG517 | THEORY AND DESIGN OF ADVANCED CONTROL SYSTEMS | 3.0 |
| EENG519 | ESTIMATION THEORY AND KALMAN FILTERING | 3.0 |
| EENG527 | WIRELESS COMMUNICATIONS | 3.0 |
| EENG589 | DESIGN AND CONTROL OF WIND ENERGY SYSTEMS | 3.0 |
| MEGN544 | ROBOT MECHANICS: KINEMATICS, DYNAMICS, AND CONTROL | 3.0 |

## Mining and Earth Systems Track (12 hours from the course list below)

| | | |
|---|---|---|
| MNGN5XX | Big Data Analytics for Earth Resources Sciences and Engineering | 3.0 |
| MNGN512 | SURFACE MINE DESIGN | 3.0 |
| MNGN516 | UNDERGROUND MINE DESIGN | 3.0 |
| MNGN536 | OPERATIONS RESEARCH TECHNIQUES IN THE MINERAL INDUSTRY | 3.0 |
| MNGN539 | ADVANCED MINING GEOSTATISTICS | 3.0 |

## Doctor of Philosophy in Operations Research with Engineering

The ORwE PhD allows students to complete an interdisciplinary doctoral degree in Operations Research with Engineering by taking courses and conducting research in eight departments/divisions: Applied Mathematics and Statistics, Electrical Engineering, Computer Sciences, Civil and Environmental Engineering, Economics & Business, Mining Engineering, Mechanical Engineering, and Metallurgical & Materials Engineering.

## Specialty Requirements

Doctoral students develop a customized curriculum to fit their needs. The degree requires a minimum of 72 graduate credit hours that includes coursework and a thesis. Coursework is valid for nine years towards a PhD degree; any exceptions must be approved by the Director of the ORwE program and by the student's adviser.

## Credit requirements

| | |
|---|---|
| Core Courses | 24.0 |
| Area of Specialization Courses | 12.0 |
| Any Combination of Specialization Courses or Research | 12.0 |
| Research Credits | 24.0 |
| Total Semester Hrs | 72.0 |

## Research Credits

Students must complete at least 24.0 hours of research credits. The student's faculty adviser and the doctoral thesis committee must approve the student's program of study and the topic for the thesis.

## Qualifying Examination Process and Thesis Proposal

Upon completion of the appropriate core coursework, students must pass Qualifying Exams I (written, over four courses) and II (oral, consisting of a report and research presentation) to become a candidate for the PhD, ORwE specialty. Qualifying Exam I is generally taken no later than three semesters after entry into the PhD program, and Qualifying Exam II follows no more than two semesters after having passed Qualifying Exam I. The proposal defense should be completed within ten months of passing Qualifying Exam II.

## Transfer Credits

Students may transfer up to 24.0 hours of graduate-level coursework from other institutions toward the PhD degree subject to the restriction that those courses must not have been used as credit toward a Bachelor's degree. The student must have achieved a grade of B or better in all graduate transfer courses and the transfer must be approved by the student's doctoral thesis committee and the Director of the ORwE program.

Although most doctoral students will only be allowed to transfer up to 24 credits, with approval from the student's doctoral committee, exceptions may be made to allow students who have earned a specialized thesis-based master's degree in operations research or other closely related field from another university to transfer up to 36 credits in recognition of the degree. Students should consult with their academic advisors and ORwE director for details.

## Unsatisfactory Progress

In addition to the institutional guidelines for unsatisfactory progress as described elsewhere in this bulletin: Unsatisfactory progress will be assigned to any full-time student who does not pass the following prerequisite and core courses in the first three semesters of study:

| | | |
|---|---|---|
| CSCI262 | DATA STRUCTURES | 3.0 |
| ORWE586 | LINEAR OPTIMIZATION | 3.0 |
| MATH530 | STATISTICAL METHODS I | 3.0 |
| CSCI406 | ALGORITHMS | 3.0 |

Unsatisfactory progress will also be assigned to any students who do not complete requirements as specified in their admission letters. Any exceptions to the stipulations for unsatisfactory progress must be approved by the ORwE committee. Part-time students develop an approved course plan with their advisor.

## Prerequisites

Students must complete the following undergraduate prerequisite courses with a grade of B or better:

| | | |
|---|---|---|
| CSCI261 | PROGRAMMING CONCEPTS | 3.0 |
| CSCI262 | DATA STRUCTURES | 3.0 |

Required Course Curriculum

All PhD students are required to take a set of core courses that provides basic tools for the more advanced and specialized courses in the program.

| Core Courses | | |
|---|---|---|
| CSCI406 | ALGORITHMS | 3.0 |
| MEGN502 | ADVANCED ENGINEERING ANALYSIS | 3.0 |
| ORWE586 | LINEAR OPTIMIZATION | 3.0 |
| MATH530 | STATISTICAL METHODS I | 3.0 |
| MATH438 | STOCHASTIC MODELS | 3.0 |
| ORWE585 | NETWORK MODELS | 3.0 |
| ORWE588 | INTEGER OPTIMIZATION | 3.0 |
| ORWE587 | NONLINEAR OPTIMIZATION | 3.0 |
| Total Semester Hrs | | 24.0 |

Students are required to take four courses from the following list:

| Area of Specialization Courses | | |
|---|---|---|
| EBGN528 | INDUSTRIAL SYSTEMS SIMULATION | 3.0 |
| or MATH542 | SIMULATION | |
| or CSCI542 | SIMULATION | |
| CSCI555 | GAME THEORY AND NETWORKS | 3.0 |
| MATH532 | SPATIAL STATISTICS | 3.0 |
| MATH537 | MULTIVARIATE ANALYSIS | 3.0 |
| MATH582 | STATISTICS PRACTICUM | 3.0 |
| MEGN592 | RISK AND RELIABILITY ENGINEERING ANALYSIS AND DESIGN | 3.0 |
| ORWE688 | ADVANCED INTEGER OPTIMIZATION | 3.0 |
| MTGN450/ MLGN550 | STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS | 3.0 |
| EBGN560 | DECISION ANALYTICS | 3.0 |
| EENG517 | THEORY AND DESIGN OF ADVANCED CONTROL SYSTEMS | 3.0 |
| CSCI562 | APPLIED ALGORITHMS AND DATA STRUCTURES | 3.0 |
| ORWE686 | ADVANCED LINEAR OPTIMIZATION | 3.0 |
| MNGN536 | OPERATIONS RESEARCH TECHNIQUES IN THE MINERAL INDUSTRY | 3.0 |
| MNGN538 | GEOSTATISTICAL ORE RESERVE ESTIMATION | 3.0 |
| EBGN509 | MATHEMATICAL ECONOMICS | 3.0 |
| MNGN538 | GEOSTATISTICAL ORE RESERVE ESTIMATION | 3.0 |
| EBGN509 | MATHEMATICAL ECONOMICS | 3.0 |
| EBGN575 | ADVANCED MINING AND ENERGY ASSET VALUATION | 3.0 |
| MATH531 | STATISTICAL METHODS II | 3.0 |

| | | |
|---|---|---|
| 5XX/6XX | Special Topics (Requires approval of the advisor and OrwE program director) | 3.0 |

## Mines' Combined Undergraduate / graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any 400+ level courses that count towards the undergraduate degree requirements as "Elective Coursework" or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a "B-" or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

## Courses

**ORWE559. SUPPLY CHAIN MANAGEMENT. 3.0 Semester Hrs.**
(II) Due to the continuous improvement of information technology, shorter life cycle of products, rapid global expansion, and growing strategic relationships, supply chain management has become a critical asset in today?s organizations to stay competitive. The supply chain includes all product, service and information flow from raw material suppliers to end customers. This course focuses on the fundamental concepts and strategies in supply chain management such as inventory management and risk pooling strategies, distribution strategies, make-to-order/make-to-stock supply chains, supplier relationships and strategic partnerships. It introduces quantitative tools to model, optimize and analyze various decisions in supply chains as well as real-world supply chain cases to analyze the challenges and solutions. 3 hours lecture; 3 semester hours.

**ORWE585. NETWORK MODELS. 3.0 Semester Hrs.**
(I) We examine network flow models that arise in manufacturing, energy, mining, transportation and logistics: minimum cost flow models in transportation, shortest path problems in assigning inspection effort on a manufacturing line, and maximum flow models to allocate machine-hours to jobs. We also discuss an algorithm or two applicable to each problem class. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. 3 hours lecture; 3 semester hours.

**ORWE586. LINEAR OPTIMIZATION. 3.0 Semester Hrs.**
(I) We address the formulation of linear programming models, linear programs in two dimensions, standard form, the Simplex method, duality theory, complementary slackness conditions, sensitivity analysis, and multi-objective programming. Applications of linear programming models include, but are not limited to, the areas of manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. Offered every other year. 3 hours lecture; 3 semester hours.

**ORWE587. NONLINEAR OPTIMIZATION. 3.0 Semester Hrs.**
(I) This course addresses both unconstrained and constrained nonlinear model formulation and corresponding algorithms (e.g., Gradient Search and Newton's Method, and Lagrange Multiplier Methods and Reduced Gradient Algorithms, respectively). Applications of state-of-the-art hardware and software will emphasize solving real-world engineering problems in areas such as manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with an algorithm such as MINOS) these optimization problems is introduced. Offered every other year. 3 hours lecture; 3 semester hours.

**ORWE588. INTEGER OPTIMIZATION. 3.0 Semester Hrs.**
(I) This course addresses the formulation of integer programming models, the branch-and-bound algorithm, total unimodularity and the ease with which these models are solved, and then suggest methods to increase tractability, including cuts, strong formulations, and decomposition techniques, e.g., Lagrangian relaxation, Benders decomposition. Applications include manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. Offered every other year. 3 hours lecture; 3 semester hours.

**ORWE686. ADVANCED LINEAR OPTIMIZATION. 3.0 Semester Hrs.**
(II) As an advanced course in optimization, we expand upon topics in linear programming: advanced formulation, the dual simplex method, the interior point method, algorithmic tuning for linear programs (including numerical stability considerations), column generation, and Dantzig-Wolfe decomposition. Time permitting, dynamic programming is introduced. Applications of state-of-the-art hardware and software emphasize solving real-world problems in areas such as manufacturing, mining, energy, transportation and logistics, and the military. Computers are used for model formulation and solution. Offered every other year. Prerequisite: MEGN586. 3 hours lecture; 3 semester hours.

**ORWE688. ADVANCED INTEGER OPTIMIZATION. 3.0 Semester Hrs.**
(II) As an advanced course in optimization, we expand upon topics in integer programming: advanced formulation, strong integer programming formulations (e.g., symmetry elimination, variable elimination, persistence), in-depth mixed integer programming cuts, rounding heuristics, constraint programming, and decompositions. Applications of state-of-the-art hardware and software emphasize solving real-world problems in areas such as manufacturing, mining, energy, transportation and logistics, and the military. Computers are used for model formulation and solution. Prerequisite: MEGN588. 3 hours lecture; 3 semester hours. Offered every other year.

## Director and Professor

Alexandra Newman

# Petroleum Reservoir Systems

## Degree Offered

- Professional Masters in Petroleum Reservoir Systems (Non-Thesis)

## Program Description

The Professional Masters in Petroleum Reservoir Systems (PMPRS) is a coursework-based (non-thesis) degree designed for individuals who have petroleum industry experience and are interested in deepening their knowledge across the disciplines of geology, geophysics, and petroleum engineering.

Teaching assistant and research assistant positions are not available for PMPRS students.

Enrollment is open for Fall and Spring semesters. The degree typically takes 3 semesters (1.5 years) to complete. Students may apply to the program through any of the three participating departments: the Department of Geophysics, the Department of Geology and Geological Engineering, or the Department of Petroleum Engineering.

## Program Requirements

The Professional Masters in Petroleum Reservoir Systems (PMPRS) (Non-Thesis) degree is designed for individuals who have petroleum industry experience and are interested in increasing their knowledge across the disciplines of geology, geophysics, and petroleum engineering.

Teaching assistant and research assistant positions are not available for PMPRS students.

Enrollment is open for Fall and Spring semesters. The degree typically takes 3 semesters (1.5 years) as no summer courses are available. Students may enroll part-time.

## Mines' Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any courses that count towards the graduate degree requirements as either "Required Coursework" or "Elective Coursework", may be used for the purposes of double counting at the discretion of the advisor (MS Non-Thesis) or thesis committee (MS Thesis or PhD). These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit.

The PMPRS program requires a minimum of 30 credit hours. Up to 9 credit hours may be at the 400 level. All other credits toward the degree must be 500 level or above.

*(A) 1 course (3.0 hours) selected from the following:*

| | | |
|---|---|---|
| GPGN/PEGN419 | INTRODUCTION TO FORMATION EVALUATION AND WELL LOGGING | 3.0 |
| GPGN519/ PEGN504 | ADVANCED FORMATION EVALUATION | 3.0 |

*(B) 2 courses (6.0 hours) selected from the following:*

| | | |
|---|---|---|
| GEGN/GPGN/ PEGN503 | INTEGRATED EXPLORATION AND DEVELOPMENT | 3.0 |
| GEGN/GPGN/ PEGN504 | INTEGRATED EXPLORATION AND DEVELOPMENT | 3.0 |
| GEOL609 | ADVANCED PETROLEUM GEOLOGY | 3.0 |

*(C)* 3 additional courses (9.0 hours) must consist of one course each from the 3 participating departments

*(D)* The remaining 4 courses (12.0 hours) may consist of graduate courses from any of the three participating departments or other courses approved by the committee. Up to 6 hours may consist of independent study, including an industry project.

## Prerequisites

Students must possess one of the three backgrounds below in order to apply for the program.

Geology and Geological Engineering:

- General Geology
- Structural Geology
- Mineralogy
- Petrology
- Stratigraphy
- Chemistry (2 semesters)
- Mathematics (2 semesters of calculus)
- An additional science course (other than geology) or advanced mathematics
- Physics (2 semesters)

Geophysics and Geophysical Engineering:

- Physics (2 semesters)
- Mathematics (at least 2 semesters of Calculus, 1 semester of Differential Equations)
- Applied Geophysics (GPGN314, or course work or professional equivalent)
- Geophysical Computing/Computational Geophysics
- Stratigraphy
- Structural Geology

Petroleum Engineering:

- Rock properties
- Reservoir fluid properties
- Drilling engineering
- Structural geology or sedimentology/stratigraphy
- Petroleum production
- Reservoir engineering
- Chemistry (2 semesters)
- Mathematics (3 semesters of calculus; 1 semester of differential equations)
- Physics (2 semesters)
- Fluid mechanics
- Thermodynamics

- Mechanics of materials
- Statics

## Director and Professor

Stephen A. Sonnenberg, Charles Boettcher Distinguished Chair in Petroleum Geology

# Quantitative Biosciences and Engineering

## Degrees Offered

- Master of Science in Quantitative Biosciences and Engineering (Thesis)
- Master of Science in Quantitative Biosciences and Engineering (Non-Thesis)
- Doctor of Philosophy in Quantitative Biosciences and Engineering

## Program Description

The graduate program in quantitative biosciences and engineering brings together faculty across the Mines campus working on diverse areas of biology to educate students, with at least a Bachelor of Science degree in engineering or science, in the diverse field of biology. Biology deals broadly with life on this planet, the human organism and its health, and harnessing biological processes to produce fuels, chemicals, and consumer products. Thus, biology in general and human health and well-being in particular are important application areas for virtually all other areas of science, technology and engineering. This is reflected in the fact that any academic discipline exists today with a bio-prefix, such as biophysics, biochemistry, bioengineering, mathematical biology, computational biology, systems biology, structural biology, biomedicine, biomaterials, biomechanics, bioinformatics, biological chemistry, geobiology, environmental biology, microbiology to name just a few. Similarly, health is included in many labels, e.g. digital healthcare, health economics, health informatics. Educating students at the interfaces of biology, health and engineering with other disciplines is a primary goal of this program.

Many departments at Mines jointly administer this cross-departmental program in interdisciplinary biosciences. The program co-exists alongside strong disciplinary programs, in chemistry and geochemistry, chemical and biochemical engineering, physics, computer science, mathematics and statistics, mechanical engineering and metallurgical and materials engineering, civil and environmental engineering, economics, geology and geological engineering and geophysics, and thus draws from the strengths of these programs through close links and joint courses. For administrative purposes, the student will reside in the advisor's home academic department. The student's graduate committee will have final approval of the course of study.

## Fields of Research

Research at Mines in this rapidly growing field currently includes but is not limited to the following general areas:

- Laser Design and Imaging
- Biofuels and Metabolic Engineering
- Omics and Systems Biology
- Environmental Toxicology and Microbiology
- Biosensors and Devices
- Biotechnology
- Biomechanics
- Biofluid mechanics
- Bioinformatics and Computational Biology
- Tissue Engineering & Biomaterials
- Physical Biochemistry
- Biophysics and Analytical Methodology Development
- Digital Healthcare
- Mathematical Biology

More than 45 faculty members across the Mines campus participate in this program, which will in the future also involve faculty of nearby collaborating institutions and scientists from the biotech/healthcare industry.

## Program Requirements

For admission, students may enter with biology or health related undergraduate degrees of with a technical degree, e.g. in engineering, mathematics, or computer science. Ideally, students with a technical major will either have one of the biology related minors form Mines, or demonstrate the equivalent background, e.g., through a biology or health related minor at another institution. Current Mines undergraduate students have the option to apply to the Office of Graduate Studies for the 4+1 combined program while pursuing their undergraduate degree.

Each of the three degree programs (non-thesis MS, thesis-based MS, and PhD) require the successful completion of three mandatory core courses for a total of 10 credit hours.

| | | |
|---|---|---|
| BIOL5XX | CELL BIOLOGY AND BIOCHEMISTRY Course not yet created. See advisor for course numbers. | 4.0 |
| BIOL5XX | APPLIED BIOINFORMATICS Course not yet created. See advisor for course numbers. | 3.0 |
| BIOL5XX | SYSTEMS BIOLOGY Course not yet created. See advisor for course numbers. | 3.0 |
| Total Semester Hrs | | 10.0 |

**List of Electives:**

Students must also take different numbers of electives, as per the degree chosen (see below). The current list of available electives is shown here but is dynamic. We expect the number of graduate level electives to increase over the time as this and other bio-related programs on campus evolve and expand. This list will therefore be updated annually subject to approval by the program's curriculum committee.

| | | |
|---|---|---|
| CBEN432 | TRANSPORT PHENOMENA IN BIOLOGICAL SYSTEMS | 3.0 |
| CBEN531 | IMMUNOLOGY FOR SCIENTISTS AND ENGINEERS | 3.0 |
| CBEN570 | INTRODUCTION TO MICROFLUIDICS | 3.0 |
| CEEN501 | LIFE CYCLE ASSESSMENT | 3.0 |
| CEEN560 | MOLECULAR MICROBIAL ECOLOGY AND THE ENVIRONMENT | 3.0 |
| CEEN562 | ENVIRONMENTAL GEOMICROBIOLOGY | 3.0 |
| CEEN566 | MICROBIAL PROCESSES, ANALYSIS AND MODELING | 3.0 |
| CEEN570 | WATER AND WASTEWATER TREATMENT | 3.0 |
| CHGN429 | BIOCHEMISTRY II | 3.0 |

| | | |
|---|---|---|
| CSCI562 | APPLIED ALGORITHMS AND DATA STRUCTURES | 3.0 |
| CSCI575 | MACHINE LEARNING | 3.0 |
| MATH572 | MATHEMATICAL AND COMPUTATIONAL NEUROSCIENCE | 3.0 |
| MEGN531 | PROSTHETIC AND IMPLANT ENGINEERING | 3.0 |
| MEGN532 | EXPERIMENTAL METHODS IN BIOMECHANICS | 3.0 |
| MEGN535 | MODELING AND SIMULATION OF HUMAN MOVEMENT | 3.0 |
| MEGN536 | COMPUTATIONAL BIOMECHANICS | 3.0 |
| MEGN537 | PROBABILISTIC BIOMECHANICS | 3.0 |
| MTGN570 | BIOCOMPATIBILITY OF MATERIALS | 3.0 |
| MTGN572 | BIOMATERIALS | 3.0 |
| PHGN433 | BIOPHYSICS | 3.0 |

## Master of Science in Quantitative Biosciences and Engineering (Thesis Option)

Here, the student conducts an in-depth research project with one of the participating faculty members who are currently accepting masters degree students. The Master of Science degree requires a minimum of 30 semester hours of acceptable course work and thesis research credits. The student must also submit a thesis and pass the Thesis Defense examination before the Thesis Committee.

| | |
|---|---|
| Core Courses | 10.0 |
| Electives | 8.0 |
| BIOL707 Research | 12.0 |
| Total Semester Hrs | 30.0 |

## Master of Science in Quantitative Biosciences and Engineering (Non-Thesis Option)

Here, the student can opt to conduct a case study instead of a full-fledged research project. The case studies can be chosen from projects provided by program faculty, local industry or academic partners. Students can also opt to enroll in further electives instead of conducting an independent study where this is more in line with their career goals. The Master of Science degree requires a minimum of 30 semester hours of acceptable course work and project credits.

| | |
|---|---|
| Core Courses | 10.0 |
| Electives | 14.0 |
| BIOL599 Independent Study | 6.0 |
| Total Semester Hrs | 30.0 |

## Doctor of Philosophy in Quantitative Biosciences and Engineering

The Doctor of Philosophy degree requires a minimum of 72.0 hours of course and research credit including at least 24 credits in coursework and at least 24 credits in research:

| | |
|---|---|
| Core Courses | 10.0 |
| Electives | 14.0 |
| BIOL707 Research | 24.0 |
| Electives or BIOL707 Research | 24.0 |
| Total Semester Hrs | 72.0 |

## Checklist

The program is interdisciplinary and it is therefore expected that there will be diverse backgrounds in the students admitted to this program. To ensure that all fundamental knowledge is adequately present, candidates may need to complete courses, which depend on the candidates' backgrounds. For example, a student with an experimental biology background needs to take programming courses. The courses are thus individualized for each candidate based on their previous experience and research activities to be pursued where applicable. Some candidates may already possess this background information. In such circumstances, the candidate's Thesis Committee may award credit for previous experience. These courses can be at the undergraduate level but do not count towards the 30 credits in the case of the Masters and 72 credits in case of the PhD degrees. Students with sufficient background can start taking graduate level classes counting towards the graduate degree in their junior year, but the majority will do so in their senior year. The program will be flexible given the expected diverse backgrounds of the students, and will offer bootcamp style activities at the beginning of each core class in order to account for the differences in backgrounds, where students from one background will help teach students with other backgrounds to acquire complementary skills.

## PhD Qualifying Process

**Core Curriculum** – The three required core classes must be completed in the first two full academic years for all doctoral candidates, except where remedial classes or prerequisites need to be taken prior. Students must obtain a grade of B- or better in each class and have a cumulative GPA of 3.0 or higher to be eligible to take the qualifying examination at the end of the succeeding spring semester. If not allowed to complete the qualifying examination at the end of the spring semester, students will be discouraged from the PhD program and encouraged, rather, to finish with a Masters degree

**PhD Qualifying Examination** – All first-year Quantitative Biosciences and Engineering PhD students are expected to successfully complete the qualifying examination at the end of the first year to remain in good standing in the program. The examination covers material from the core curriculum plus the theoretical background of their chosen area of research. If a student performs below the expectations of the faculty administering the oral exam, a student may need to finish with a Masters degree.

**PhD Thesis Proposal** – A student's PhD thesis committee administers the PhD Thesis Proposal defense. The PhD proposal defense should occur no later than the student's fourth semester. While the proposal itself should focus on the central topic of the student's research, during the proposal defense, candidates may expect to receive a wide range of questions from the Committee. This would include all manner of questions directly related to the proposal. Candidates, however, should also expect questions related to the major concept areas of Biology within the context of a candidate's research focus. The Committee formally reports the results of the PhD proposal defense to the Quantitative Biosciences and Engineering Program Director using the Committee Reporting form developed by the Office of Graduate Studies.

Upon completion of these steps and upon completion of all required coursework, candidates are admitted to candidacy. Following successful completion of coursework and the PhD qualifying process, candidates must also submit a thesis and successfully complete the PhD Defense of Thesis examination before the PhD Thesis Committee.

## Mines’ Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines’ combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their Quantitative Biosciences and Engineering (QBE) Graduate Program.. Any 400+ level courses that count towards the undergraduate degree requirements as "Elective Coursework" or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor (MS Non-Thesis) or thesis committee (MS Thesis of PhD). These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit.

## Courses

**BIOL598. SPECIAL TOPICS IN BIOLOGY. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**BIOL599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**BIOL707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

## Advising Faculty

Joel Bach, Professor of Mechanical Engineering

Cecilia Diniz Behn, Assistant Professor of Applied Mathematics & Statistics

Steven Boyes, Associate Professor of Chemistry

Nanette Boyle, Assistant Professor of Chemical and Biological Engineering

John Bradford, Professor of Geophysics

Kevin Cash, Assistant Professor of Chemical and Biological Engineering

Anuj Chauhan, Professor of Chemical and Biological Engineering

Dylan Domaille, Assistant Professor of Chemistry

Christopher Higgins, Associate Professor of Civil and Environmental Engineering

Judith Klein-Seetharaman, Director of Biosciences and Bioengineering

Melissa Krebs, Associate Professor of Chemical and Biological Engineering

Lokender Kumar, Research Assistant Professor of Physics

Amy Landis, Professor of Civil and Environmental Engineering

Karin Leiderman-Gregg, Assistant Professor of Applied Mathematics & Statistics

Terry Lowe, Research Professor of Materials and Metallurgical Engineering

David Marr, Professor of Chemical and Biological Engineering

Christine Morrison, Assistant Professor of Chemistry

Steve Pankavich, Associate Professor of Applied Mathematics & Statistics

Tony Petrella, Associate Professor of Mechanical Engineering

Andrew Petruska, Assistant Professor of Mechanical Engineering

Matt Posewitz, Professor of Chemistry

James Ranville, Professor of Chemistry

James Rosenblum, Research Assistant Professor of Civil and Environmental Engineering

Susanta Sarkar, Assistant Professor of Physics

Josh Sharp, Associate Professor of Civil and Environmental Engineering

Anne Silverman, Associate Professor of Mechanical Engineering

Dendy Sloan, Emeritus Professor of Chemical and Biological Engineering

John Spear, Professor of Civil and Environmental Engineering

Jeff Squier, Professor of Physics

Blake Stamps, Research Assistant Professor of Civil and Environmental Engineering

Amadeu Sum, Professor of Chemical and Biological Engineering

Brian Trewyn, Associate Professor of Chemistry

Shubham Vyas, Assistant Professor of Chemistry

Hua Wang, Associate Professor of Computer Science

Kim Williams, Professor of Chemistry

Xioli Zhang, Assistant Professor of Mechanical Engineering

## Teaching Faculty

Linda Battalora, Teaching Professor of Petroleum Engineering

Kristine Csavina, Teaching Professor of Mechanical Engineering

Laura Legault, Teaching Assistant Professor of Computer Science

Cynthia Norrgran, eaching Associate Professor of Chemical and Biological Engineering

Josh Ramey, Teaching Associate Professor of Chemical and Biological Engineering

Jeffrey Schowalter, Teaching Professor of Electrical Engineering

# Quantum Engineering

## Degrees Offered

- Graduate Certificate in Quantum Engineering
- Master of Science (Non-Thesis)
- Master of Science (Thesis)

## Program Requirements

Quantum Engineering is an interdisciplinary program that seeks to equip students for careers in emerging technologies based on quantum entanglement. It encompasses a wide range of disciplines that include physics, materials science, computer science, and mathematics, and is necessarily a collaborative effort among many Mines departments. Two Master's degrees and one Graduate certificate are offered.

For both degrees and the graduate certificate, Quantum Engineering has two "tracks" as summarized below. The Quantum Engineering Hardware (QEH) track will focus on experimental techniques relevant to quantum technology, while the Quantum Engineering Software (QES) track will focus on theory, algorithms and simulation. Students must choose a track to complete the program, but they may take courses from both tracks provided they meet the prerequisite requirements.

## Graduate Certificate Curriculum Requirements:

The certificate option consists of three of the four new courses, plus one additional elective chosen from the above list, for a total of 12 credit hours.

## Graduate Certificate, Software Track

| | | |
|---|---|---|
| PHGN519 | FUNDAMENTALS OF QUANTUM INFORMATION | 3.0 |
| CSCI581 | QUANTUM PROGRAMMING | 3.0 |
| PHGN545 | QUANTUM MANY-BODY PHYSICS | 3.0 |
| Elective | | 3.0 |
| Total Semester Hrs | | 12.0 |

## Graduate Certificate, Hardware Track

| | | |
|---|---|---|
| PHGN519 | FUNDAMENTALS OF QUANTUM INFORMATION | 3.0 |
| PHGN435/535 | INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY | 3.0 |
| EENG/PHGN532 | LOW TEMPERATURE MICROWAVE MEASUREMENTS FOR QUANTUM ENGINEERING | 3.0 |
| Elective | | 3.0 |
| Total Semester Hrs | | 12.0 |

## MS Degree Curriculum Requirements:

A Master of Science in Quantum Engineering will consist of 30 total credit hours. Students may choose a thesis or non-thesis option for this degree. For the thesis option, 9 credit hours out of the 30 are devoted to thesis research leading to an acceptable Master's thesis. Students choosing the non-thesis option will devote all 30 credit hours to coursework. Regardless of the option chosen, 9 of the coursework credit hours will be devoted to the required core classes for the chosen track.

Reflecting the interdisciplinary nature of the program, we strongly recommend to our students that at least 9 total credits of the MS degree coursework should come from courses in a department outside of the student's undergraduate major. The required core courses, if outside of the student's major, would count towards this recommendation. Our guiding philosophy is that the problem of building a quantum computer is a complex, interdisciplinary one which requires contributions from a vast array of subfields, and young scientists who appreciate this will likely have a far better perspective on the field than those who do not.

## MS Non-Thesis Software Track

| | | |
|---|---|---|
| PHGN519 | FUNDAMENTALS OF QUANTUM INFORMATION | 3.0 |
| CSCI581 | QUANTUM PROGRAMMING | 3.0 |
| PHGN545 | QUANTUM MANY-BODY PHYSICS | 3.0 |
| Electives | | 21.0 |
| Total Semester Hrs | | 30.0 |

## MS Non-Thesis Hardware Track

| | | |
|---|---|---|
| PHGN519 | FUNDAMENTALS OF QUANTUM INFORMATION | 3.0 |
| PHGN435/535 | INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY | 3.0 |
| EENG532 | LOW TEMPERATURE MICROWAVE MEASUREMENTS FOR QUANTUM ENGINEERING | 3.0 |
| Electives | | 21.0 |
| Total Semester Hrs | | 30.0 |

## MS Thesis Software Track

| | | |
|---|---|---|
| PHGN519 | FUNDAMENTALS OF QUANTUM INFORMATION | 3.0 |
| CSCI581 | QUANTUM PROGRAMMING | 3.0 |
| PHGN545 | QUANTUM MANY-BODY PHYSICS | 3.0 |
| Electives | | 12.0 |
| PHGN707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 9.0 |
| Total Semester Hrs | | 30.0 |

## MS Thesis Hardware Track

| | | |
|---|---|---|
| PHGN519 | FUNDAMENTALS OF QUANTUM INFORMATION | 3.0 |
| PHGN435/535 | INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY | 3.0 |
| EENG/PHGN532 | LOW TEMPERATURE MICROWAVE MEASUREMENTS FOR QUANTUM ENGINEERING | 3.0 |
| Electives | | 12.0 |
| PHGN707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 9.0 |
| Total Semester Hrs | | 30.0 |

## Coursework Details:

QES students will be required to take these courses in the following sequence:

In the Fall:

- PHGN519, Fundamentals of Quantum Information

In the Spring:

- CSCI581, Quantum Programming
- PHGN541, Quantum Many-Body Physics

QEH students will be required to take these courses in the following sequence:

In the Fall:

- PHGN519, Fundamentals of Quantum Information

In the Spring:

- PHGN 435/535, Interdisciplinary Silicon Processing Laboratory
- PHGN532, Low Temperature Microwave Measurements for Quantum Applications

## Approved Electives:

| | | |
|---|---|---|
| **Physics Electives** | | |
| PHGN440 | SOLID STATE PHYSICS | 3.0 |
| PHGN441 | SOLID STATE PHYSICS APPLICATIONS AND PHENOMENA | 3.0 |
| PHGN466/566 | MODERN OPTICAL ENGINEERING | 3.0 |
| PHGN480 | LASER PHYSICS | 3.0 |
| PHGN520 | QUANTUM MECHANICS I | 3.0 |
| PHGN521 | QUANTUM MECHANICS II | 3.0 |
| PHGN530 | STATISTICAL MECHANICS | 3.0 |
| PHGN550 | NANOSCALE PHYSICS AND TECHNOLOGY | 3.0 |
| PHGN585 | NONLINEAR OPTICS | 3.0 |
| **Computer Science Electives** | | |
| CSCI542 | SIMULATION | 3.0 |
| CSCI563 | PARALLEL COMPUTING FOR SCIENTISTS AND ENGINEERS | 3.0 |
| CSCI564 | ADVANCED COMPUTER ARCHITECTURE | 3.0 |
| CSCI571 | ARTIFICIAL INTELLIGENCE | 3.0 |
| CSCI474 | INTRODUCTION TO CRYPTOGRAPHY | 3.0 |
| CSCI575 | MACHINE LEARNING | 3.0 |
| CSCI580 | ADVANCED HIGH PERFORMANCE COMPUTING | 3.0 |
| **Electrical Engineering Electives** | | |
| EENG509 | SPARSE SIGNAL PROCESSING | 3.0 |
| EENG417/517 | MODERN CONTROL DESIGN | 3.0 |
| EENG526 | ADVANCED ELECTROMAGNETICS (Metallurgy and Material Engineering Electives) | 3.0 |
| EENG528 | COMPUTATIONAL ELECTROMAGNETICS | 3.0 |
| EENG529 | ACTIVE RF & MICROWAVE DEVICES | 3.0 |
| EENG530 | PASSIVE RF & MICROWAVE DEVICES | 3.0 |
| EENG617 | INTELLIGENT CONTROL SYSTEMS | 3.0 |
| EENG618 | NONLINEAR AND ADAPTIVE CONTROL | 3.0 |
| **Metallurgy and Material Engineering Electives** | | |
| MTGN456 | ELECTRON MICROSCOPY | 2.0 |
| MTGN505 | CRYSTALLOGRAPHY AND DIFFRACTION | 3.0 |
| **Materials Science Electives** | | |
| MLGN593 | BONDING, STRUCTURE, AND CRYSTALLOGRAPHY | 3.0 |
| **Applied Mathematics and Statistics Electives** | | |
| MATH408 | COMPUTATIONAL METHODS FOR DIFFERENTIAL EQUATIONS | 3.0 |
| MATH436 | ADVANCED STATISTICAL MODELING | 3.0 |
| MATH438 | STOCHASTIC MODELS | 3.0 |
| MATH510 | ORDINARY DIFFERENTIAL EQUATIONS AND DYNAMICAL SYSTEMS | 3.0 |
| MATH551 | COMPUTATIONAL LINEAR ALGEBRA | 3.0 |

## Mines' Combined Undergraduate / Graduate Degree Program:

As with many other graduate programs, students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their quantum engineering MS degree. Any 400+ level courses that count towards the undergraduate degree requirements as "Elective Coursework" or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a "B-" or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

# Robotics

## Degrees Offered

- Graduate Certificate in Robotics
- Master of Science in Robotics (Non-Thesis)
- Master of Science in Robotics (Thesis)
- Doctor of Philosophy in Robotics

The Robotics program offers the degrees of Master of Science and Doctor of Philosophy in Robotics. The non-thesis MS is designed to prepare candidates for industry careers in robotics. The thesis MS and PhD degrees are designed to prepare students for research careers. The graduate certificate is intended for working professionals.

Combined Program: The Robotics program also offers combined BS+MS degrees. These degrees offer an expedited graduate school application process and allow students to begin graduate coursework while still finishing their undergraduate degree requirements.

## Admission

## Mines' Combined Undergraduate / Graduate Degree Program

Current Mines undergraduate students are encouraged to apply for the combined program once they have taken five or more technical classes at Mines (classes transferred from other universities will not be considered). This requirement may be met by any 200-level or above course with a CSCI, MEGN, or EENG prefix, excluding field session and senior design courses.

Students enrolled in Mines' Combined Undergraduate/Graduate Program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any courses that count towards the graduate degree requirements as either "Required Coursework" or "Elective Coursework", as defined below, may be used for the purposes of double counting at the discretion of the advisor (MS Non-Thesis) or thesis committee (MS Thesis or PhD). These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit.

## MS and PhD

The minimum requirements for admission to the MS and PhD degrees in Robotics are:

• Applicants must have a Bachelor's degree, or equivalent, from an accredited institution with a grade-point average of 3.0 or better on a 4.0 scale prior to matriculating into the Robotics degree program.

• Students are expected to have completed the following coursework: (1) two semesters of calculus, (2) differential equations, and (3) data structures.  The Robotics graduate admissions committee may require that students who do not meet this expectation demonstrate competency or take remedial coursework.  Such coursework may not count toward the graduate degree. The committee will decide whether to recommend regular or provisional admission.

• Graduate Record Examination (Quantitative section) score of 151 or higher (or 650 on the old scale). Applicants who have graduated with a computer science, engineering, or math degree from Mines within the past five years are not required to submit GRE scores.

• TOEFL score of 79 or higher (or 550 for the paper-based test or 213 for the computer- based test) for applicants whose native language is not English. In lieu of a TOEFL score, and IELTS score of 6.5 or higher will be accepted.

• For the PhD program, prior research experience is desired but not required.

**Transfer Credit** Graduate level courses taken at other universities for which a grade equivalent to a "B" or better was received will be considered for transfer credit with approval of the Advisor and/or Thesis Committee, and home department head, as appropriate. Transfer credits must not have been used as credit toward a Bachelor degree. For the MS degree, no more than nine credits may transfer. For the PhD degree, up to 24 credit hours of courses may be transferred. In lieu of transfer credit for individual courses, students who enter the PhD program with a thesis-based master's degree from another institution may transfer up to 36 hours in recognition of the course work and research completed for that degree.

**400-level Courses** As stipulated by the Mines Graduate School, students may apply toward graduate degree requirements a maximum of nine (9.0) semester hours of department- approved 400-level course work.

**Advisor and Thesis Committee** Students must have an Advisor from the Robotics faculty to direct and monitor their academic plan, research, and independent studies. Advisors must be full-time permanent members of the faculty. In this context, full-time permanent members of the faculty are those that hold the rank of professor, associate professor, assistant professor, research professor, associate research professor or assistant research professor. Upon approval by the Graduate Dean, adjunct faculty, teaching faculty, visiting professors, emeritus professors and off-campus representatives may be designated additional co-advisors. A list of Robotics faculty by rank is available in the faculty tab of the catalog.

The department of the Advisor is the student's home department.

Master of Science (thesis option) students in Robotics must have at least three members on their Thesis Committee. In addition to the institutional requirements, at least one committee member who is not the advisor must be Robotics faculty.

Robotics PhD Thesis Committees must have at least four members. In addition to the institutional requirements, at least one committee member who is not the advisor must be Robotics faculty.

## Program Requirements

## Graduate Certificate

The graduate certificate will require 12 credit hours of coursework. Table 3 summarizes the requirements for the graduate certificate. Please note: only 3 of the 12 credit hours can include coursework at the 400-level or lower to achieve the Graduate Certificate.

| | | |
|---|---|---|
| Robotics Core | Four courses, one from each focus area's core course list | 12.0 |
| Total Semester Hrs | | 12.0 |

Table 3: Robotics Graduate Certificate Summary Requirements

## MS Degrees

The MS degrees will require 30 credit hours, with thesis options substituting for electives.

**MS Non-Thesis (MS-NT)** Students must take 30 credit hours of coursework to complete the degree. Table 1 summarizes the requirements for the MS-NT degree.

| | | |
|---|---|---|
| Robotics Core (Breadth) | Four courses, one from each focus area's core course list | 12.0 |
| Robotics Electives (Depth) | Two courses from robotics course list | 6.0 |
| Technical Electives | Four courses in any participating robotics department (CSCI, EENG, MEGN) | 12.0 |
| Total Semester Hrs | | 30.0 |

Table 1: Robotics MS Non-Thesis Summary Requirements

**MS Thesis** Students must take 21 credit hours of coursework and 9 credit hours of MS thesis research to complete the degree. Table 2 summarizes the requirements for the MS Thesis degree.

At the conclusion of the MS Thesis, the student must make a formal presentation and defense of their thesis research. A student must “pass” this defense to earn an MS degree.

| | | |
|---|---|---|
| Robotics Core (Breadth) | Four courses, one from each focus area's core course list | 12.0 |
| Robotics Electives (Depth) | Two courses from robotics course list | 6.0 |
| Technical Electives | One course in any participating robotics department (CSCI, EENG, MEGN) | 3.0 |
| MEGN707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 9.0 |
| Total Semester Hrs | | 30.0 |

Table 2: Robotics MS Thesis Summary Requirements

## PhD Degree

The Robotics PhD requires 36 credit hours of coursework, plus 36 research credit hours. Table 4 summarizes the coursework requirements and specific courses are listed below. PhD students must additionally complete a qualifying examination, a thesis proposal, and a thesis defense.

| | | |
|---|---|---|
| Robotics Core (Breadth) | Four courses, one from each focus area's core course list | 12.0 |
| Robotics Electives (Depth) | Four Courses from robotics course list | 12.0 |
| Technical Electives | Four courses in any participating robotics department (CSCI, EENG, MEGN) | 12.0 |
| MEGN707 | GRADUATE THESIS / DISSERTATION RESEARCH CREDIT | 36.0 |
| Total Semester Hrs | | 72.0 |

Table 4: Robotics PhD Summary Requirements

## Robotics PhD Qualifying Examination

The Robotics PhD Qualifying Examination will test a student’s ability to conduct research in their chosen area. The qualifier will have two components: a coursework component and a research component.

**Coursework Qualifier** To satisfy the coursework component of the qualifier, the student must complete their four selected robotics focus courses area with a minimum grade of “B” in each class.

**Research Qualifier** The research qualifier consists of a research project. Robotics PhD students must take the qualifying examination by the end of their fourth semester (typically by the end of their second year). The examination will be evaluated by a committee consisting of at least the student’s advisor, a robotics-affiliated faculty (see section 5.1.2), and one additional faculty member.

For the qualifier, the student will conduct a literature review of 30-40 papers and perform a research project approaching the level necessary for a conference publication. The research project must be approved by the advisor and committee and will likely be some combination of the following:

• Design, analyze and/or simulate a novel robot system;

• Design and evaluate new algorithms or systems for an important research problem;

• Develop a new research software system;

• Solve a set of theoretical problems.

The deliverables will be a literature review (3-4 pages, IEEE style [4]), a research report (4-5 pages, IEEE style), and a research presentation (30 minutes to present, plus questions) delivered to the committee.

At the conclusion of the qualifier presentation, each committee member will vote their evaluation as one of “Strong Support”, “Weak Support”, or “Do not support.” The student must receive at least two “Strong Support” votes to pass. In the case the student does not pass, the committee may decide to offer a “conditional pass” based on extra conditions, such as revisions to the report or additional experiments, the student must perform to pass the qualifier. The committee will set an explicit deadline for student to complete the extra conditions. If the student does not meet the extra conditions as determined by the committee by the deadline, the “conditional pass” becomes a “fail.” If the student does not pass the qualifier on their first attempt (inclusive of a conditional pass), they may make one additional attempt to pass; the same conditional pass procedure may also be applied to the second attempt. A student who fails the qualifier on the second attempt may not continue in the program.

## Robotics PhD Proposal and Defense

After passing the qualifying examination, the student must prepare a written thesis proposal and present it formally to the student’s Thesis Committee and other interested faculty. Typically, the proposal will take place within 24 months of the student completing the qualifier.

The committee for the thesis proposal and defense will follow institutional requirements. Additionally, at least one committee member who is not the advisor must be robotics-affiliated faculty.

At the conclusion of the student's PhD program, the student must make a formal presentation and defense of their thesis research. A student must "pass" this defense to earn a PhD degree. Typically, the defense will take place within 24 months of the student completing the thesis proposal.

## Robotics Course List

## Perception

**Core Courses**

| | | |
|---|---|---|
| CSCI507 | INTRODUCTION TO COMPUTER VISION | 3.0 |
| CSCI573 | HUMAN-CENTERED ROBOTICS | 3.0 |
| EENG519 | ESTIMATION THEORY AND KALMAN FILTERING | 3.0 |

**Elective Courses**

| | | |
|---|---|---|
| CSCI508 | ADVANCED TOPICS IN PERCEPTION AND COMPUTER VISION | 3.0 |

## Cognition

**Core Courses**

| | | |
|---|---|---|
| CSCI404 | ARTIFICIAL INTELLIGENCE | 3.0 |
| CSCI575 | MACHINE LEARNING | 3.0 |
| CSCI534 | ROBOT PLANNING AND MANIPULATION | 3.0 |

**Elective Courses -** None.

## Action

**Core Courses**

| | | |
|---|---|---|
| MEGN540 | MECHATRONICS | 3.0 |
| MEGN544 | ROBOT MECHANICS: KINEMATICS, DYNAMICS, AND CONTROL | 3.0 |
| MEGN545 | ADVANCED ROBOT CONTROL | 3.0 |
| EENG517 | THEORY AND DESIGN OF ADVANCED CONTROL SYSTEMS | 3.0 |

**Elective Courses**

| | | |
|---|---|---|
| EENG417 | MODERN CONTROL DESIGN | 3.0 |
| EENG515 | MATHEMATICAL METHODS FOR SIGNALS AND SYSTEMS | 3.0 |

## Interaction & Society

**Core Courses**

| | | |
|---|---|---|
| CSCI5XX | HUMAN-ROBOT INTERACTION | 3.0 |
| CSCI532 | ROBOT ETHICS | 3.0 |

**Elective Courses**

| | | |
|---|---|---|
| CSCI5XX | LINGUISTIC HUMAN-ROBOT INTERACTION | 3.0 |

## Additional Robotics Electives

| | | |
|---|---|---|
| CSCI406 | ALGORITHMS | 3.0 |
| CSCI561 | THEORY OF COMPUTATION | 3.0 |
| CSCI562 | APPLIED ALGORITHMS AND DATA STRUCTURES | 3.0 |
| CSCI565 | DISTRIBUTED COMPUTING SYSTEMS | 3.0 |
| CSCI572 | COMPUTER NETWORKS II | 3.0 |
| EENG411 | DIGITAL SIGNAL PROCESSING | 3.0 |
| EENG511 | CONVEX OPTIMIZATION AND ITS ENGINEERING APPLICATIONS | 3.0 |
| EENG521 | NUMERICAL OPTIMIZATION | 3.0 |
| MEGN586 | LINEAR OPTIMIZATION | 3.0 |
| MEGN587 | NONLINEAR OPTIMIZATION | 3.0 |
| MEGN588 | INTEGER OPTIMIZATION | 3.0 |
| MEGN686 | ADVANCED LINEAR OPTIMIZATION | 3.0 |
| MEGN688 | ADVANCED INTEGER OPTIMIZATION | 3.0 |

# Space Resources

## Degrees Offered

- Graduate Certificate in Space Resources - online
- Master of Science in Space Resources (Non-Thesis) - online
- Doctor of Philosophy in Space Resources - residential and online

## Program Description

Since the 1990s, Colorado School of Mines has been a leading institution for the study of space resources and their utilization. It has also become a destination for space scientists and engineers, government agencies, aerospace companies, entrepreneurs, the mining and minerals industry, financial and legal experts, and policy makers to discuss all topics related to space resources.

In recent years, growing interest in the identification, extraction, and utilization of space resources by space agencies and the private sector has been driven by an awareness that further development of space travel will be enabled through extraction of extraterrestrial materials for the production of propellants to enable more affordable and flexible transportation, for facilities construction, and for life support. The broad topic of space resources brings together many fields in which Mines has a strong presence, including remote sensing, geomechanics, mining, materials/metallurgy, robotics/automation, advanced manufacturing, electrochemistry, solar and nuclear energy, and resource economics and policy.

In this light, Mines has launched a first-of-its-kind multi-disciplinary graduate program in Space Resources to offer a Graduate Certificate and Master of Science and PhD degrees for college graduates and professionals interested in this emerging arena. The program focuses on developing core knowledge and gaining design practices in systems for responsible exploration, extraction, use, and stewardship of resources in the Solar System.

## Space Resources Program Requirements

The interdisciplinary Space Resources program is targeted to train recent graduates, as well as professionals interested in expanding their knowledge and skills to address the opportunities and challenges in space resource exploration, extraction, and utilization. Space Resources touches on physical sciences, engineering, and the social science fields. Thus, this program engages faculty members from many academic departments at Mines.

The graduate program for Space Resources includes the following degree options:

- a 12-credit-hour Graduate Certificate in Space Resources offered online,
- a 30-credit Master of Science Non-Thesis (MS-NT) degree in Space Resources offered online,
- a PhD program in Space Resources requiring 36 credit hours of coursework, 36 credit hours of research, and a doctoral dissertation. The PhD program can be completed on campus and also online for those students approved to conduct their research remotely by their advisor and dissertation committee.

A 12-credit hour Graduate Certificate requires 6 credit hours from two core courses and 6 credit hours chosen from other core or elective courses. For the MS-NT and PhD degrees, in addition to 6 credit hours from two core courses, 6 credit hours from a seminar class and two core project-based courses are required. These project courses allow students to conduct a design, system, or economic analysis focused on the exploration, extraction, utilization, and responsible stewardship of space resources.

Beyond that, MS-NT and PhD students will take 18 credit hours chosen from a variety of elective courses on critical areas in space resources, such as: Remote Sensing and Resource Assessment; Extraction, Processing, and Resource Utilization; Power and Energy; Robotics, Autonomy, and Communications, and Economics, Law, and Policy.

A student who completes a PhD in Space Resources will possess all the training of a Master's degree holder with further specialization in one or more areas within the space resources field. The completed doctoral dissertation will make original contributions to the field.

## Mines' Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any 400+ level courses that count towards the undergraduate degree requirements as "Elective Coursework" or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a "B-" or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

## Graduate Certificate

This option requires students to take a minimum of 12 credit hours exclusively online. Table 1 lists the courses that will comprise the curriculum for the Graduate Certificate.

**Table 1** – Required courses for 12-credit-hour Graduate Certificate in Space Resources

| | | |
|---|---|---|
| SPRS501 | SPACE RESOURCES FUNDAMENTALS | 3.0 |
| SPRS502 | SPACE SYSTEMS ENGINEERING | 3.0 |
| SPRS ELECTIVE | SPACE RESOURCES ELECTIVE | 3.0 |
| SPRS ELECTIVE | SPACE RESOURCES ELECTIVE | 3.0 |
| Total Semester Hrs | | 12.0 |

Online elective courses can be taken from a variety of important topics on space resources, such as: planetary geology, space operations, remote sensing, resource economics, materials extraction, advanced manufacturing, space law and policy, and other topics which continue to be introduced as relevant subjects are identified and new courses developed (see Table 3).

## Master of Science (Non-Thesis)

The Master of Science degree program is exclusively non-thesis (MS-NT) and online. The MS-NT degree program coursework requires 30 credit hours as laid out in Table 2. For students coming into the program with previous Master or PhD degrees, up to 9 credit hours of relevant courses can be transferred after approval from the Space Resources program director in consultation with faculty members of the program.

Table 2 – Required courses for the 30-credit-hour online Master of Science Non-Thesis degree in Space Resources

| | | |
|---|---|---|
| SPRS501 | SPACE RESOURCES FUNDAMENTALS | 3.0 |
| SPRS502 | SPACE SYSTEMS ENGINEERING | 3.0 |
| SPRS503 | SPACE RESOURCES SEMINAR | 1.0 |
| SPRS591 | SPACE RESOURCES PROJECT I | 2.0 |
| SPRS592 | SPACE RESOURCES PROJECT II | 3.0 |
| SPRS ELECTIVE | SPACE RESOURCES ELECTIVE | 3.0 |
| SPRS ELECTIVE | SPACE RESOURCES ELECTIVE | 3.0 |
| SPRS ELECTIVE | SPACE RESOURCES ELECTIVE | 3.0 |
| SPRS ELECTIVE | SPACE RESOURCES ELECTIVE | 3.0 |
| SPRS ELECTIVE | SPACE RESOURCES ELECTIVE | 3.0 |
| SPRS ELECTIVE | SPACE RESOURCES ELECTIVE | 3.0 |
| Total Semester Hrs | | 30.0 |

The 18 credit hours of elective courses can be selected from any of the various courses listed on Table 3. These courses provide students with a broad interdisciplinary coverage of critical topics in space resources. Additional courses are being developed and introduced on various relevant subjects.

Table 3 – Current elective courses for all degree options of the Space Resources program (additional topics are being introduced as relevant subjects are identified and new courses developed).

| | | |
|---|---|---|
| GEOL410 | PLANETARY GEOLOGY | 3.0 |
| GPGN570 | APPLICATIONS OF SATELLITE REMOTE SENSING | 3.0 |
| AMFG501 | ADDITIVE MANUFACTURING | 3.0 |
| CEEN501 | LIFE CYCLE ASSESSMENT | 3.0 |
| SPRS504 | ECONOMICS OF SPACE RESOURCES | 3.0 |
| SPRS598A | INTERNATIONAL SPACE LAW AND POLICY | 3.0 |
| SPRS598B | SPACE OPERATIONS | 3.0 |
| SPRS599 | INDEPENDENT STUDY IN SPACE RESOURCES | 3.0 |

## PhD in Space Resources

The PhD degree program requires 72 total credit hours, consisting of at least 36 credit hours of courses beyond the BS and at least 36 research credit hours. PhD coursework beyond the MS degree program will not be restricted other than approved by the student's advisor and dissertation committee. The PhD degree allows for both on-campus and online options. The latter requires approval by the student advisor and dissertation committee who will review and approve if the research project can be conducted remotely.

Students who enter the PhD program with an MS degree in a relevant engineering, science, economics, or business field are expected to take at least 12 credit hours of core courses. For students coming into the program with a previous Master Non-Thesis, up to 24 credit hours of relevant courses can be transferred after approval from the Space Resources program director in consultation with the program faculty. For students with a previous Master with Thesis or PhD degrees, up to 30 credit hours of relevant courses can be approved to be transferred, however the student will still be required to take 12 credit hours from core courses. If a total of 30 credit hours of transferred courses are approved and 12 credit hours of core Space Resources taken, the number of research credit hours can be lowered to a minimum of 30 for a total of at least 72 hours of course and research work for graduation.

In accordance with other PhD programs at Mines, students in the Space Resources PhD degree program must successfully complete qualifying examinations, defend their written dissertation proposal, and write and defend a doctoral dissertation, in addition to their course and research work. PhD research is aimed at fundamentally advancing the state of the art in Space Resources. PhD students are expected to submit the dissertation work for at least two archival publications in scholarly journals and present research findings in at least one professional conference. Students are also required to participate in the Space Resources seminar series both by attending seminars of distinguished speakers and by presenting their research on no less than an annual basis.

PhD students in the Space Resources program will be advised by a faculty advisor affiliated with the program and by an interdisciplinary Doctoral committee, which must contain a majority of faculty affiliated with the program. The PhD degree program culminates in a research dissertation that provides significant scholarly contribution to the Space Resources field.

Because of the interdisciplinary nature of Space Resources, there is significant flexibility in the Program's curriculum and faculty instructors to allow for students with a diverse range of backgrounds to enter and succeed in their targeted degree program.

Graduates from the Space Resources program will be prepared to serve the growing needs of industry, government, and academia to identify, extract, process, and utilize space resources. Students will have a broad, multi-disciplinary understanding of the overall flow of activities in the development of space resources, a high-level exposure to the different science, engineering, economics, and business disciplines involved in each phase and an understanding of the current state of affairs in space resources across academia, government, and the private sector. A Master's degree holder will be able to make immediate contributions to any government agency or company pursuing technical activities related to space resources. PhD degree holders will be able to pursue academic positions or contribute as a specialist in industry or government.

## Courses

**SPRS501. SPACE RESOURCES FUNDAMENTALS. 3.0 Semester Hrs.**
(I, II) This course provides an overview of the space resources field, including the current knowledge of available resources in the Solar System, extraction and utilization systems under development, economic and technical feasibility studies, legal and policy issues, and space exploration architectures that may be enabled by utilizing extraterrestrial resources in the near future. The course will build broad knowledge and develop confidence in problem solving in the space resources field. 8-week online course. 3 hours lecture; 3 semester hours. Prerequisite: Working knowledge of physical sciences, engineering fields, or economics at an advanced undergraduate level, with basic numerical analysis skills using a programming language or spreadsheet calculations.

**SPRS502. SPACE SYSTEMS ENGINEERING. 3.0 Semester Hrs.**
This course conveys the fundamentals of the systems engineering process as applied to large, complex space systems. It is intended for graduate students with various backgrounds. The students will become familiar with full scope of the systems engineering process from requirements definition, system design, system analysis through system verification. The process will be illustrated with real-world examples from current space systems with an emphasis on systems relevant to the development of space resources. 8-week online course.

**SPRS503. SPACE RESOURCES SEMINAR. 1.0 Semester Hr.**
(I, II) The Space Resources Seminar will engage students in the program with current research and developments related to space resources. Students will assess the importance and relevance to the space resources field in the near-, medium-, or long-term of topics covered in lectures presented by technical experts from a variety of disciplines. They will report and analyze events, news, and research publications and develop scientific, technical, and economic arguments for their impact and relevance to the space resources field, while also responding thoughtfully and critically to other students' contributions. Students will synthesize the information presented during the entire course by contributing in teams to a final report with an analysis of the most important developments in the science, technology, economics and policy of space resources during the course period. 8-week online course. 1 hour seminar; 1 semester hour.

**SPRS504. ECONOMICS OF SPACE RESOURCES. 3.0 Semester Hrs.**
This course provides an overview of economics and business topics that are commonly found in the space industries. Students will build a basic knowledge of economics, finance, and business issues that are relevant to space resource markets and industries. The big picture is to help provide perspective on what investors or the financial officers at companies are investing in and planning for in or around the space industry.

**SPRS591. SPACE RESOURCES PROJECT I. 2.0 Semester Hrs.**
This course will provide graduate students in the program with directed team-based project learning by exploring the design, planning, and analysis of missions, processes, systems, science, business, and economics for space resources assessment, extraction, and/or utilization. The course will meet formally online once a week for one hour and include a 10-15 minute discussion on relevant design aspects of space mission, processes, and/or systems. In this regard, it will build on content learned in the Space Resources Fundamentals, Space Systems Engineering, and other courses in the Space Resources Program. Students will collaborate in multi-disciplinary teams, typically of up to 5 students. Teams will be advised by a course instructor with significant industrial aerospace design experience and supported by faculty affiliated with the Space Resources program from relevant disciplines on campus. For teams with students in space resource economics, detailed economic analysis will be incorporated into those projects. Student teams will prepare a preliminary design, planning and analysis report early in the semester, one interim progress report, and a final report and project presentation. 16-week online course.

**SPRS592. SPACE RESOURCES PROJECT II. 3.0 Semester Hrs.**
This course will provide graduate students in the MS-NT and PhD programs in Space Resources with an independent design and analysis project. This project will be guided by the course instructor and a technical advisor, will enable the student to delve deeply into a particular system related to space resources prospecting, extraction, processing, and/or utilization of the science of potential resources into business and economics cases for space resources . As much as possible, projects will be coordinated with industrial or government agency partners who are collaborating with the program. The course will involve weekly online meetings where ideas are exchanged and progress discussed within the context of design and analysis principles learned in the prerequisite course. Students will be partnered with a faculty member affiliated with the Space Resources Program. The student will prepare a final report and presentation to present to industry collaborators, space resources faculty, and other students in the course. The final report and/or presentation as appropriate will be converted to a journal or conference publication and/or presentation and resources from the program will support student costs for publishing and/or presenting the work. 16-week online course.

**SPRS598. SPECIAL TOPICS IN SPACE RESOURCES. 6.0 Semester Hrs.**
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**SPRS599. INDEPENDENT STUDY IN SPACE RESOURCES. 0.5-6 Semester Hr.**
Students can do Individual research or special projects supervised by a faculty member. The student and instructor will agree on the subject matter, content, and credit hours. Prerequisites: Independent Study form must be completed and submitted to the Registrar.

**SPRS707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**
(I, II, S) Research credit hours required for completion of Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit. Prerequisite: Instructor approval.

## Director and Professor of Practice

ANGEL ABBUD-MADRID, Professor of Practice

## Professor of Practice

GEORGE SOWERS

## Research Assistant Professor

CHRISTOPHER DREYER

# Underground Construction and Tunnel Engineering

## Degrees Offered

- Master of Science in Underground Construction and Tunnel Engineering, Thesis
- Master of Science in Underground Construction and Tunnel Engineering, Non-Thesis
- Doctor of Philosophy in Underground Construction and Tunnel Engineering
- Graduate Certificate in Underground Construction and Tunnel Engineering

## Program Description

Underground Construction and Tunnel Engineering (UCTE) is an interdisciplinary field primarily involving civil engineering, geological engineering and mining engineering, and secondarily involving mechanical engineering, electrical engineering, geophysics, geology and others. UCTE deals with the design, construction, rehabilitation and management of underground space including caverns, shafts and tunnels for commercial, transportation, water and wastewater use. UCTE is a challenging field involving complex soil and rock behavior, groundwater conditions, excavation methods, construction materials, structural design flow, heterogeneity, and very low tolerance for deformation due to existing infrastructure in urban environments. Students pursuing a graduate degree in UCTE will gain a strong and interdisciplinary foundation in these topics.

The graduate degree program in UCTE is offered jointly by the Departments of Civil & Environmental Engineering (CEE), Geology & Geological Engineering (GEGN), and Mining Engineering (MN). UCTE faculty from each department are collectively responsible for the operations of the program. Participating students reside in one of these departments, typically the home department of their advisor.

Program coursework is selected from multiple departments at Mines (primarily CEE, GEGN, MN) and is approved for each student by the student's advisor and graduate committee. To achieve the MS degree, students may elect the non-thesis option based upon coursework and an independent study report tied to a required internship. Students may alternatively select the thesis option comprised of coursework and a research project performed under the guidance of a UCTE faculty advisor and presented in a written thesis approved by the student's thesis committee.

PhD students are expected to complete a combination of coursework and novel, original research under the guidance of a UCTE faculty advisor and doctoral committee, which culminates in a significant scholarly contribution to a specialized field in UCTE. Full-time enrollment is encouraged and leads to the greatest success, although part-time enrollment is permissible for working professionals. All graduate students must complete the full-time, on-campus residency requirements described in the general section of the Graduate Catalog.

## Program Requirements

## Masters and PhD in Underground Construction and Tunneling Engineering

| **MS Non-Thesis Option:** |
| --- |
| Coursework - 27.0 credit hours |
| Independent Study* - 3.0 credit hours |
| UCTE Seminar - 0.0 credit hours |
| Total Hours - 30.0 |

*Where possible, MS non-thesis students should complete a practically-focused independent study in partnership with an industry partner; this may include student participation in an industry internship on a UCTE project.

| **MS Thesis Option:** |
| --- |
| Coursework - 24.0 credit hours |
| Research (minimum) - 6.0 credit hours |
| UCTE Seminar - 0.0 credit hours |
| Total Hours - 30.0 |

MS Thesis students must write and successfully defend a thesis report of their research. Ideally, MS thesis research should be industry-focused and should provide value to industry UCTE practice.

| **PhD Option** |
| --- |
| Coursework (beyond BS degree) - 42.0 credit hours |
| Independent Study* - 3.0 credit hours |
| Research (minimum) - 24.0 credit hours |
| UCTE Seminar - 0.0 credit hours |
| Total Hours - 72.0 |

PhD students must also successfully complete qualifying examinations, write and defend a dissertation proposal, and write and defend a doctoral dissertation. PhD research is aimed at fundamentally advancing the state of the art in UCTE. PhD students are expected to submit the dissertation work for publication in scholarly journals and disseminate findings throughout industry periodicals.

*PhD students are expected to complete an internship of approximately 3 months in duration (with a design firm, contractor, owner, equipment manufacturer, etc., and preferably on a UCTE job site). If an internship is not available or if the student has sufficient industry experience (determined by advisor and committee), the student may complete an industry-focused research project via independent study with a UCTE faculty member and industry partner culminating with a written report and presentation.

## Mines' Combined Undergraduate/Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any courses that count towards the graduate degree requirements as either "Required Coursework" or "Elective Coursework", as defined below, may be used for the purposes of double counting at the discretion of the advisor (MS Non-Thesis) or thesis committee (MS Thesis or PhD). These courses must have been passed with a "B-" or better and meet all other University, Department, Division, and Program requirements for graduate credit.

## Required Coursework

The following 18 credit hours are required for the MS (thesis and non-thesis) and PhD degrees.

| | | |
|---|---|---|
| GEGN468 | ENGINEERING GEOLOGY AND GEOTECHNICS | 4.0 |
| GEGN561 | UNDERGROUND CONSTRUCTION ENGINEERING LABORATORY 1 | 0.5 |
| GEGN562 | UNDERGROUND CONSTRUCTION ENGINEERING LABORATORY 2 | 0.5 |
| CEEN523 | UNDERGROUND CONSTRUCTION ENGINEERING IN SOFT GROUND | 4.0 |
| MNGN504 | UNDERGROUND CONSTRUCTION ENGINEERING IN HARD ROCK | 3.0 |
| CEEN512 | SOIL BEHAVIOR | 3.0 |
| MNGN509 | CONSTRUCTION ENGINEERING AND MANAGEMENT | 3.0 |

All MS and PhD students are required to attend the UCTE seminar series (0 h); no registration is required.

MS non-thesis and PhD students must complete a practically-focused project (separate from the thesis in the case of the PhD degree), registering as an independent study in the home department of the faculty advisor (CEEN599, GEGN599, or MNGN599). This requirement may be waived for students with sufficient UC&T industry experience.

## Elective Coursework

The following courses may be taken as electives to complete the MS and PhD course requirements. Students may petition for other courses not listed below to count towards the elective requirement. In addition, MS or PhD students may petition one of the following courses to substitute for a required course if one of the required courses is not offered during the student's course of study or if a student has sufficient background in one of the required course topics. All petitions must be made to the student's advisor and thesis committee.

| | | |
|---|---|---|
| CEEN415 | FOUNDATION ENGINEERING | 3.0 |
| CEEN506 | FINITE ELEMENT METHODS FOR ENGINEERS | 3.0 |
| CEEN510 | ADVANCED SOIL MECHANICS | 3.0 |
| CEEN541 | DESIGN OF REINFORCED CONCRETE STRUCTURES II | 3.0 |
| CEEN599 | INDEPENDENT STUDY | 0.5-6 |
| GEGN466 | GROUNDWATER ENGINEERING | 3.0 |
| GEGN563 | APPLIED NUMERICAL MODELLING FOR GEOMECHANICS | 3.0 |
| GEGN573 | GEOLOGICAL ENGINEERING SITE INVESTIGATION | 3.0 |
| GEGN581 | ANALYTICAL HYDROLOGY | 3.0 |
| GEGN672 | ADVANCED GEOTECHNICS | 3.0 |
| GEGN673 | ADVANCED GEOLOGICAL ENGINEERING DESIGN | 3.0 |
| GEGN599 | INDEPENDENT STUDY IN ENGINEERING GEOLOGY OR ENGINEERING HYDROGEOLOGY | 0.5-6 |
| MNGN424 | MINE VENTILATION | 3.0 |
| MNGN506 | DESIGN AND SUPPORT OF UNDERGROUND EXCAVATIONS | 3.0 |
| MNGN507 | ADVANCED DRILLING AND BLASTING | 3.0 |
| MNGN524 | ADVANCED MINE VENTILATION | 3.0 |
| MNGN590 | MECHANICAL EXCAVATION IN MINING | 3.0 |
| MNGN599 | INDEPENDENT STUDY | 0.5-6 |

## Thesis Committee Requirements

Students must meet the general committee requirements listed in the graduate bulletin. In addition, the student's advisor or co-advisor must be a UCTE faculty member. In the case that a student is co-advised, the co-advisor will serve as an additional committee member above and beyond the minimum committee requirements.

The committee for PhD students enrolled in the UCTE degree program shall be composed of a minimum of four (4) faculty members:

- The student's advisor
- Two core UCTE faculty members representing two of three core UCTE departments (Civil Engineering, Geological Engineering, Mining Engineering)
- An "external" committee member, who has no connection to the student or their research (this member should not come from any of the three core UCTE departments, other than in exceptional circumstances); this member will chair the committee and must be a permanent CSM faculty member

Additional committee members may be added as appropriate, including off-campus representatives from industry and academia.

Given the interdisciplinary nature of the UCTE degree program, no more than two (2) of the four PhD committee members can be from the same department.

## Qualifying Exam Procedure

Students enrolled in the UCTE PhD program are expected to have passed a qualifying exam by the end of their first year of study. This qualifying exam will be administered by a sub-committee of UCTE faculty. If a UCTE faculty member is serving on this sub-committee for the qualifying exam of a student they are advising, they will act as a non-voting member for that exam.

The intention of the qualifying exam is to evaluate the student's capacity to undertake PhD-level research; this includes their ability to think critically, to apply core UCTE concepts to abstract problems, and to develop methods to test scientific hypotheses. The format of the exam will include a written component and an oral exam, approximately two hours in length. Prior to their oral exam, the student will be assigned two tasks:

- The student will be provided a research topic which has some relevance to their research, but is not directly related. The student will be required to submit an 8-10 page literature review on this topic to their committee twenty-four (24) hours prior to their oral exam. During the oral exam, the student will be asked questions related to their literature review.
- The student will be provided with four (4) questions which will represent a significant portion of their oral exam. These questions will be designed to assess the student's ability to consider analysis, design, and research questions critically. The core UCTE curriculum

will serve as foundational knowledge for these questions. As the student's response will be oral (no written response to the questions will be submitted), the questions will require students to suggest problem solving approaches rather than to directly implement them. Based on the student's response to each question, follow-up questions will be asked.

If the student fails their first qualifying exam, they may be given an opportunity to attempt a second qualifying exam at the discretion of the committee who administered their first exam. If the student fails their second qualifying exam, they will not be admitted to PhD candidacy.

## Prerequisites

Students will enter the UCTE programs with a variety of backgrounds. Because the UCTE degrees are engineering degrees, the required prerequisite courses for the UCTE programs include basic engineering coursework, and specifically: (1) Strength of Materials or Mechanics of Materials, and (2) Fluid Mechanics. These prerequisite courses may be completed during the first semester of the graduate program if approved by the UCTE program faculty. It is permissible for students to take graduate level courses without having completed the corresponding undergraduate courses to address areas where key competencies are lacking, such as in soil mechanics, rock mechanics, structural analysis or groundwater engineering. However, students may choose to complete undergraduate courses in these topics prior to or concurrently during enrollment in the required graduate program courses. With the exception of the 400-level coursework allowed by the graduate catalog, undergraduate level coursework to address any prerequisite deficiencies does not count towards the requirements of the MS or PhD degrees. Students should consult with UCTE faculty for guidance in this matter.

## Program Requirements

## Graduate Certificate in Underground Construction and Tunnel Engineering

The interdisciplinary Graduate Certificate in Underground Construction and Tunnel Engineering (UCTE) is comprised of the three signature courses listed below. The two anchor courses teach UCTE in hard rock and soft ground while the remaining course teaches construction management principles.

Applicants for the certificate are required to have an undergraduate degree in science or engineering, with geotechnical and mechanics of materials coursework, to be admitted into the Certificate program. Students working toward the UCTE Graduate Certificate are required to successfully complete 10 credit hours, as detailed below. The courses taken for the Graduate Certificate can be used towards a Master's or PhD degree at Mines.

| | | |
|---|---|---|
| CEEN523 | UNDERGROUND CONSTRUCTION ENGINEERING IN SOFT GROUND | 4.0 |
| MNGN504 | UNDERGROUND CONSTRUCTION ENGINEERING IN HARD ROCK | 3.0 |
| MNGN509 | CONSTRUCTION ENGINEERING AND MANAGEMENT | 3.0 |
| Total Semester Hrs | | 10.0 |

## Director

Michael Mooney, UCTE Director, Grewcock Distinguished Chair

## Department of Civil & Environmental Engineering

Marte Gutierrez, J.R. Paden Distinguished Chair & Professor

Reza Hedayat, Assistant Professor

Panos Kiousis, Associate Professor

Michael Mooney, Grewcock Distinguished Chair & Professor

Shiling Pei, Assistant Professor

## Department of Geology & Geological Engineering

Paul Santi, Professor

Gabriel Walton, Assistant Professor

Wendy Zhou, Associate Professor

## Department of Mining Engineering

Ray Henn, Adjunct Professor

Rennie Kaunda, Assistant Professor

Eunhye Kim, Assistant Professor

Hugh Miller, Associate Professor

Priscilla Nelson, Department Head & Professor

# Policies & Procedures

## Standards, Codes of Conduct

Students can access campus rules and regulations, including the student code of conduct, alcohol policy, public safety and parking policies, the distribution of literature and free speech policy, and a variety of others by visiting the School's policy website (https://inside.mines.edu/POGO-Policies-Governance/). We encourage all students to review the website and expect that students know and understand the campus policies, rules and regulations as well as their rights as a student. Questions and comments regarding the above mentioned policies can be directed to the Dean of Students located in the Student Life Office in the Ben Parker Student Center.

For emphasis, the following policies are included or identified in this section:

- Student Honor Code
- Policy on Academic Integrity/Misconduct
- Policy Prohibiting Sexual Harassment, Sexual Violence, and Interpersonal Violence
- Unlawful Discrimination Policy
- Alcohol and Other Drugs Education and Prevention Policy
- Electronic Communications (E-mail) Policy
- Student Complaint Process
- Access to Student Records
- Posthumous Degree Awards
- Equal Opportunity, Equal Access, and Affirmative Action
    - Title IX @ Mines (http://inside.mines.edu/POGO-Title-IX/)
    - SpeakUP@Mines

Please note: Any policy or procedure updates during the term will be reflected in the Mines Policy Library (http://inside.mines.edu/POGO-Policies/) and those versions shall control.

## Student Honor Code

**1.0 PREAMBLE**

The students of Colorado School of Mines have adopted the following Student Honor Code in order to establish a high standard of student behavior at Mines. The Code may only be amended through a student referendum supported by a majority vote of the Mines student body. Mines students shall be involved in the enforcement of the Code through their participation in the Student Conduct Appeals Board.

**2.0 CODE**

Mines students believe it is our responsibility to promote and maintain high ethical standards in order to ensure our safety, welfare, and enjoyment of a successful learning environment. Each of us, under this Code, shall assume responsibility for our behavior in the area of academic integrity. As a Mines student, I am expected to adhere to the highest standards of academic excellence and personal integrity regarding my schoolwork, exams, academic projects, and research endeavors. I will act honestly, responsibly, and above all, with honor and integrity in all aspects of my academic endeavors at Mines. I will not misrepresent the work of others as my own, nor will I give or receive unauthorized assistance in the performance of academic coursework. I will conduct myself in an ethical manner in my use of the library, computing center, and all other school facilities and resources. By practicing these principles, I will strive to uphold the principles of integrity and academic excellence at Mines. I will not participate in or tolerate any form of discrimination or mistreatment of another individual.

## Policy on Academic Integrity/Misconduct

**1.0 ACADEMIC INTEGRITY**

The Colorado School of Mines (Mines) affirms the principle that all individuals associated with the Mines academic community have a responsibility for establishing, maintaining, and fostering an understanding and appreciation for academic integrity. In broad terms, this implies protecting the environment of mutual trust within which scholarly exchange occurs, supporting the ability of the faculty to fairly and effectively evaluate every student’s academic achievements, and giving credence to the university’s educational mission, its scholarly objectives, and the substance of the degrees it awards. The protection of academic integrity requires there to be clear and consistent standards, as well as confrontation and sanctions when individuals violate those standards. The Colorado School of Mines desires an environment free of any and all forms of academic misconduct and expects students to act with integrity at all times.

**2.0 POLICY ON ACADEMIC MISCONDUCT**

Student Academic Misconduct arises when a student violates the principle of academic integrity and/or when a student aids and abets in the commission of academic misconduct. Academic misconduct may also occur when a student is negligent in their reasonable responsibilities as a student to be aware of or proactively confirm or clarify appropriate conduct with coursework, assignments or exams, and subsequently proceeds in a manner befitting of misconduct. Such behavior erodes mutual trust, distorts the fair evaluation of academic achievements, violates the ethical code of behavior upon which education and scholarship rest, and undermines the credibility of the university.

Because of the serious institutional and individual ramifications, student misconduct arising from violations of academic integrity is not tolerated at Mines. If a student is found to have engaged in such misconduct sanctions such as change of a grade, loss of institutional privileges, or academic suspension or dismissal may be imposed.

The Dean of Students Office administers this faculty-approved policy. Within the Dean of Students Office, two administrators will facilitate the separate aspects of the policy, including the initial resolution and appeal process, in order to remain impartial with respect to potential appeals whilst simultaneously providing procedural guidance to faculty and students.

**Forms of Misconduct**. As a guide, some of the more common forms of academic misconduct are noted below. This list is not intended to be all-inclusive; rather, the list is illustrative of practices the Mines faculty have deemed inappropriate.

1. **Dishonest Conduct** - general conduct unbecoming a scholar. Examples include issuing misleading statements; withholding

pertinent information; submitting previously graded work as new and/or original without acknowledgement and permission; not fulfilling, in a timely fashion, previously agreed to projects or activities; and verifying as true, things that are known to the student not to be true or verifiable.

2. **Plagiarism** - presenting the work of another as one's own. This is usually accomplished through the failure to acknowledge the borrowing of ideas, data, or the words of others. Examples include submitting as one's own work the work of another student, a ghost writer, or a commercial writing service; quoting, either directly or paraphrased, a source without appropriate acknowledgment; and using figures, charts, graphs or facts without appropriate acknowledgment. Inadvertent or unintentional misuse or appropriation of another's work is nevertheless plagiarism.
3. **Falsification/Fabrication** - inventing or altering information. Examples include inventing or manipulating data or research procedures to report, suggest, or imply that particular results were achieved from procedures when such procedures were not actually undertaken or when such results were not actually supported by the pertinent data; false citation of source materials; reporting false information about practical, laboratory, or clinical experiences; falsifying attendance or participation; submitting false excuses for absence, tardiness, or missed deadlines; and, altering previously submitted examinations.
4. **Tampering** - interfering with, forging, altering or attempting to alter university records, grades, assignments, or other documents without authorization. Examples include using a computer or a false-written document to change a recorded grade; altering, deleting, or manufacturing any academic record; and, gaining unauthorized access to a university record by any means.
5. **Cheating** - using or attempting to use unauthorized materials or aid with the intent of demonstrating academic performance through fraudulent means. Examples include copying from another student's paper or receiving unauthorized assistance on a homework assignment, quiz, test, or examination; using books, notes or other devices such as calculators, PDAs and cell phones, unless explicitly authorized; acquiring without authorization a copy of the examination before the scheduled examination; and copying reports, laboratory work or computer files from other students. Authorized materials are those generally regarded as being appropriate in an academic setting, unless specific exceptions have been articulated by the instructor.
6. **Impeding** - negatively impacting the ability of other students to successfully complete course or degree requirements. Examples include removing pages from books and removing materials that are placed on reserve in the Library for general use; failing to provide team members necessary materials or assistance; and, knowingly disseminating false information about the nature of a test or examination.
7. **Sharing Work** - giving or attempting to give unauthorized materials or aid to another student. Examples include allowing another student to copy your work; giving unauthorized assistance on a homework assignment, quiz, test or examination; providing, without authorization, copies of examinations before the scheduled examination; posting work on a website for others to see; and sharing reports, laboratory work or computer files with other students.

Additionally, individual courses may specify appropriate and/or inappropriate scholastic conduct as long as course specific guidance is not in conflict with this senior, university misconduct policy and is well known by way of advanced written distribution to all students enrolled (e.g. published course syllabus).

Allegations of misconduct brought forward by faculty must fall within with the aforementioned seven examples of common misconduct and/or be specifically and explicitly addressed in the published course materials

**3.0 PROCEDURES FOR ADDRESSING ACADEMIC MISCONDUCT**

Faculty members and thesis committees have discretion to address and resolve misconduct matters in a manner that is commensurate with the infraction and consistent with the values of the Institution. This includes imposition of appropriate academic sanctions for students involved in academic misconduct. However, in order to maintain consistency when handling such issues, if a member of the Mines' community has grounds for suspecting that a student or students have engaged in academic misconduct, they have an obligation to act on this suspicion by utilizing the following procedure:

**3.1 Notify the Dean of Students Office.** Upon suspicion of misconduct, it is the faculty member's responsibility to email the Dean of Students Office. The Dean of Students Office will provide procedural guidance to the faculty member, including pre-written email templates which the faculty may use.

Student names may be disclosed at this time, but are not necessary. Prepared sample templates and procedural guidance will consider and include appropriate accessibility language to ensure an accessible process for students and faculty, alike.

**3.2 Notify and Meet with Student(s)**. Following correspondence with the Dean of Students Office, the faculty member or thesis committee representative must meet with and inform the student(s) of the suspicions/allegations and potential charge of academic misconduct within ten (10) business days of suspecting misconduct.

This meeting allows the student the opportunity to give his/her/their perspective or explanation prior to any decision being made as to whether or not misconduct occurred. The student should be aware of the subject of the meeting and the alleged misconduct at the time of scheduling. The meeting also allows the faculty member to have a conversation with the student(s) in an effort to educate him/her/them on appropriate conduct.

Following this meeting (at end of meeting or afterward, and within the prescribed timeline), the faculty member should inform the student of their decision as to whether or not misconduct occurred. In the instance where the faculty member(s) believe misconduct occurred, the student should be explicitly informed of the nature of the misconduct (e.g. cheating, plagiarism, etc.).

The meeting can be done via telephone if needed, but a face-to-face meeting between the faculty member and student is preferred. It is recommended, but not required, that the faculty invite a neutral, silent colleague to the meeting as an impartial witness. If the student or faculty member is unable to meet because of pre-existing commitments or unforeseen priorities, the ten-day timeline may be temporarily suspended with mutual written agreement of faculty and student(s), and written approval by the Dean of Students Office prior to expiration of the deadline.

**3.3. Actions Taken; Circumstances.** The circumstances of the academic misconduct dictate the process to be followed:

3.3.1 Regular Coursework. In the case of an allegation of academic misconduct associated with **regular coursework** (including exams), if after talking with the student, the faculty member finds the student is responsible for academic misconduct the faculty member should:

- Contact the Dean of Students and his/her Department Head/Division Director to officially report the violation in writing within five (5) business days of meeting with the student (as outlined above – see 3.1). Report of a violation should detail the nature of the misconduct (e.g. cheating, plagiarism, etc.).
- The Dean of Students Office will communicate the resolution in writing to the student, the faculty member(s), appropriate members of Academic Affairs, the Office of Graduate Studies (if applicable), the student's advisor, and any additional appropriate parties including Athletics, course coordinators, or the Registrar's Office. The Dean of Students will keep official records on all students with academic misconduct violations. Disciplinary action/ sanctioning for misconduct with regular coursework:
    - 1st Offense: Zero credit (or no points) on the assignment/exam/effort. Educational sanctioning as prescribed and facilitated by the Dean of Students Office. Notation of first offense in disciplinary record.
        - Failure to comply with educational sanctioning expectations and timeline will result in immediate acceleration of offense to sanctioning prescribed with 2nd offense (F in course and inability to withdraw). Additionally, the student's disciplinary standing will also be upgraded to 2nd offense.
        - With 1st offense, faculty may choose to provide a restorative credit assignment or make-up quiz or exam wherein students can work to recover credit penalized as part of misconduct sanctioning.
    - 2nd Offense: "F" in the course and inability to withdraw. Notation of second offense in disciplinary record.
    - 3rd or Greater Offense: "F" in the course. Suspension from school for 1-year minimum (calendar year). "Suspension as a result of Academic Misconduct" permanently noted on university transcript. Return to Mines not guaranteed, and only possible by way of Mines Readmissions Committee.

3.3.2 Activities Not Part of Regular Coursework. In the case of an allegation of academic misconduct associated with **activities not a part of regular coursework** (e.g., an allegation of cheating on a comprehensive examination or academic misconduct in connection with a graduate thesis project), if after talking with the student, faculty member(s) finds the student is responsible for misconduct the faculty should:

- Contact the Dean of Students and his/her Department Head/Division Director to officially report the violation in writing within five (5) business days of meeting with the student (as outlined above – see 3.1). The Dean of Students Office will communicate the resolution in writing to the student, the faculty member(s), appropriate members of Academic Affairs, the Office of Graduate Studies (if applicable), the student's advisor, and any additional appropriate parties including Athletics, course coordinators, or the Registrar's Office. The Dean of Students will keep official records on all students with academic misconduct violations.
- Assign an outcome to the activity that constitutes failure. If appropriate, the student's advisor may also assign a grade of "PRU" (unsatisfactory progress) for research credits in which the student is enrolled. Regular institutional procedures resulting from either of these outcomes are then followed. Faculty members may impose a lesser penalty if the circumstances warrant, however, the typical sanction is failure.

3.3.3 Research Activities. In the case of an allegation of academic misconduct associated with **research activities**, investigation and resolution of the misconduct is governed by the Institution's Research Integrity Policy. The Research Integrity Policy is available as section 10.3 of the Faculty Handbook. If, after talking with the student, the faculty member feels the student is responsible for misconduct of this type, the faculty member should proceed as indicted in the Research Integrity Policy. If appropriate, the student's advisor may also assign a grade of "PRU" for research credits in which the student is enrolled. Regular institutional procedures resulting from this grade assignment are then followed.

**3.4 Student Reporting**. Students who suspect other students of academic misconduct should report the matter to the appropriate faculty member, the appropriate Department Head/Division/ Program Director, the Dean of Undergraduate Studies, the Dean of Graduate Studies or the Dean of Students. The information is then provided to the faculty member concerned.

## 4.0 STUDENT ACADEMIC MISCONDUCT APPEAL PROCESS

### 4.1 Purpose

A student may appeal a decision within certain timelines and under specific criteria. For all charges of academic misconduct, upon notification of a finding of academic misconduct and the associated penalties, the student may appeal the decision of the faculty member.

An appeal is not a second hearing of the case, but rather it is a review of the procedures followed and information presented to determine if the process provided was in accordance with the policy, or if the decision was unsupported by the evidence, as set forth below.

This appeal process governs all requests for appeal related to violations of the Academic Integrity/Misconduct Policy. Grade Appeals, residency appeals, student conduct appeals, and appeals related to research misconduct are handled through separate processes. Please see the Mines Policy website for more information on those processes.

**4.2 Grounds for Appeal**

An appeal request will be considered only if it includes the specific grounds for an appeal and the rationale that support the selected grounds. The three items listed below are the only acceptable grounds for an appeal:

- **Due Process**. To determine whether the meeting with the faculty member and the process followed was conducted fairly and in conformity with the prescribed procedures. Any procedural errors must have been so substantial as to effectively deny the student a reasonable opportunity to prepare and present information about an alleged policy violation. The student should be able to show that there would have been a different outcome if the procedural error had not occurred. Minor deviations that do not materially affect the outcome are not a basis for sustaining an appeal.
- **New Information**. To consider information or other relevant facts sufficient to alter a decision because such information was not known by the student at the time of the original conduct meeting with the faculty member.
- **Unsupported Decision**. To determine whether the decision reached by the faculty member was supported using the preponderance of evidence standard to establish that a violation of the policy occurred. This ground for appeal requires the student to show that no reasonable person could have determined that the student was responsible or could have imposed the sanctioned issued based on the available evidence.

**4.3 Submitting an Appeal Request**

Decisions reached by a faculty member may be appealed by the student. A student may file an appeal by completing a Student Conduct Appeal Form and submitting it to the Dean of Students' Office by the date stated on the original decision letter (typically seven business days). This form is available online at https://www.mines.edu/policy-library/student/ and in person at the Student Life Office. It is the student's obligation to complete the form in its entirety and provide any and all materials that she/he wishes to have considered at the time of the appeal submission. Incomplete form, late submissions, or revised requests will not be accepted. If the student's appeal request is not received by the designated deadline, the decision of the faculty member is final and no further appeal will be permitted.

**4.3.1 Appeal Request Review**. Once an appeal request is received, it is forwarded to the Dean of Students. Within five business days, the Dean of Students will review the request to determine if the acceptable grounds for an appeal have been met, if the appeal has been timely filed, and if the request is complete. After review of the request, the Dean of Students will take one of the following actions:

1. Accept the Appeal Request - See section 4.3.2 below
2. Deny the Appeal Request – The Dean of Students will notify the student that the appeal has been denied and the basis for the denial. An appeal that does not set forth sufficient grounds for appeal (as described in section 2.0 above) will be denied. In such cases, the original decision of the faculty member is considered binding upon all involved and the matter will be considered closed unless the student can provide evidence that the Dean of Students made an arbitrary decision without fully considering the information presented. If that is the case, the student requesting the appeal must notify the Associate Vice President of Student Life in writing within two business days and request that the appeal be reviewed again by the Associate Vice President of Student Life. The Associate Vice President of Student Life will review the request within two business days. The Associate Vice President of Student Life will either accept the appeal request (see section 3.2) or deny the appeal request. If the Associate Vice President of Student Life denies the appeal request, the decision is final and considered binding upon all involved.

**4.3.2 Accepted Appeal.** Once the appeal request has been accepted by the Dean of Students (or Associate Vice President of Student Life), the Dean of Students will proceed as follows:

1. Notify the student and the faculty member that the appeal has been accepted and the appeal will proceed.
2. Schedule a date and time for the appeal meeting to be held.
3. Provide the student and faculty member with an overview of the appeal process and allow them to submit any additional information related to the academic misconduct charge that they would like to be included in the appeal meeting.
4. Forward the appeal and all supporting documents to the participating members of the Student Conduct Appeals Board.

**4.4 Student Conduct Appeals Board**

The Student Conduct Appeals Board ("Board") consists of 16 members of the campus community, including 6 students, 6 faculty, and 4 staff, plus the Dean of Students as the chair. A minimum of three Board members (including 1 student and 1 faculty member) are required for all appeal meetings.

Upon acceptance of an appeal, the list of the members of the Student Conduct Appeals Board will be provided to the student and the faculty member. Both the student and the faculty member may each request the removal of one of the Board members' from participating in the appeal meeting. Upon receipt of such requests, the Dean of Students will remove the potential member from participating.

Once an appeal request is accepted and the appeal meeting scheduled, non-excluded Board members will be contacted and invited to participate at the appeal meeting. Appeals Board members have an affirmative obligation to excuse themselves if they have a conflict of interest. The Dean of Students will provide participating Board members with all pertinent information regarding the incident and appeal, including but not limited to the student's education records, the appeal request, and other information submitted by the student and the faculty member.

**4.5 Appeal Meeting**

The student and the faculty member will meet individually with the participating Student Conduct Appeals Board members during the appeal meeting. Both the student and the faculty member will be allowed to provide a brief statement and then answer questions from the Appeals Board members. The student and faculty member will not be permitted to question one another. All questioning will be done by the Board members. The Board members may, at their discretion, meet with any appropriate witnesses during the meeting. After all questioning has occurred, the student and faculty member will be excused.

**4.5.1 Recordings***.* If requested by the student or faculty member, one verbatim record, such as a recording, will be made. This recording shall be the property of Mines. If such a recording is made, a student wishing to obtain a copy of the recording must submit a request to the Dean of Students. This may be done via mail, email, or in person. Once the request has been received, the Dean of Students will provide both parties with a copy of the recording.

**4.5.2 Advisor.** The appeal meeting is an internal University judicial matter. Students are allowed to have one individual advisor (parent, lawyer, friend etc.) in the room during the appeal meeting. The advisor is not allowed to speak on the student's behalf or address the committee during the appeal meeting. He/she is only allowed to hear the information being provided to the committee, confer with the student, and offer the student advice. This individual is not permitted to represent the student or speak on the student's behalf during the appeal meeting.

**4.6 Pending Action**

Throughout the entire appeal process, and while the decision of the Dean of Students or the Student Conduct Appeals Committee is pending, the student must continue to comply with all conditions of the original decision made by the faculty member. Unless otherwise specified in the original written notification of suspension, a student may continue to attend classes while the appeal is pending.

**4.7 Decision**

At the conclusion of the appeal meeting, the Student Conduct Appeals Board will make one of the following decisions:

1. Reverse the decision of the faculty member and withdraw the charge from the student's record.
2. Affirm the decision of the faculty member and uphold the sanction(s).
3. Forward the case to the Office of Academic Affairs for further consideration: the Student Conduct Appeals Board believes that additional matters implicated in the appeal should be reviewed and considered which could include increasing or decreasing the sanctions imposed or addressing additional issues that arose through the appeal process. Recommendations for appropriate sanctions should be made by the Student Appeals Committee to the Office of Academic Affairs. The additional review and consideration will be conducted by the Dean of Undergraduate Studies or Dean of Graduate Studies, depending on the academic standing of the student requesting the appeal. The Office of Academic Affairs staff member will make a final decision that will be communicated to the student within 10 business days.

The decision made will be communicated to the student and faculty member within 24 hours of the conclusion of the appeal meeting. The decision issued by the Student Conduct Appeals Board or the Office of Academic Affairs (in matters that are forwarded for further consideration) is final and shall be considered binding upon all involved, from which no additional appeals are permitted.

*For the most up-to-date version of this procedure and appeal request forms, please see the* student section of the policy website *(*https://www.mines.edu/policy-library/student/*).*

Unlawful Discrimination Policy and Complaint Procedure

**1.0. BACKGROUND AND PURPOSE**

This policy is promulgated by the Board of Trustees of the Colorado School of Mines ("Mines") pursuant to the authority conferred upon it by CRS §23-41-104(1) in order to set forth a policy prohibiting unlawful discrimination at Mines.

**2.0 POLICY**

Mines is committed to inclusivity and access for all persons and strives to create learning and workplace environments that exclude all forms of unlawful discrimination, harassment and retaliation. Mines' commitment to non-discrimination, affirmative action, equal opportunity, and equal access is reflected in the administration of its policies, procedures, programs, and activities, as well as its efforts to achieve a diverse student body and workforce.

Discrimination on the basis of age, ancestry, creed, marital status, race, ethnicity, religion, national origin, sex, gender, gender identity, gender expression, disability, sexual orientation, genetic information, veteran status, or military service is unlawful and therefore prohibited. This prohibition applies to all students, faculty, staff, contractors, administrators, trustees, visitors, and volunteers.

This policy and its related procedures apply to Mines employees and pertain to any situation involving unlawful discrimination on the bases of age, ancestry, creed, marital status, race, ethnicity, religion, national origin, sex, gender, gender identity, gender expression, disability, sexual orientation, genetic information, veteran status, or military service. Please refer to the Unlawful Discrimination Policy Procedures for more information on the procedures utilized for resolving complaints filed under this policy.

Mines will not tolerate retaliation against Mines community members for filing complaints regarding or implicating any of these protected statuses, or otherwise participating in investigations regarding such complaints.

It is a violation of this Policy to intentionally submit a false complaint or file a complaint that is not made in good faith or to provide false or misleading information during an investigation.

**3.0 PROCEDURES FOR IMPLEMENTATION AND COMPLAINTS**

The Board of Trustees directs the President, or the President's delegates, to develop, manage, and maintain appropriate procedures and resources to implement this policy. Violators of this policy will be subject to disciplinary action, up to and including termination of employment, expulsion, and termination of contractual relationships with Mines. No one filing a complaint under this policy shall be permitted to simultaneously file a grievance under the State of Colorado Personnel Board Rules or the Colorado School of Mines Faculty Handbook against the same individual and arising out of the same event(s).

**4.0 HISTORY & REVIEW CYCLE**

***For a complete policy statement*** *and the most up-to-date procedures, please see the* policy website *(*https://inside.mines.edu/POGO-Policies-Governance/*). Promulgated by the Mines Board of Trustees on March 13, 1992. Amended by the Mines Board of Trustees on June 10, 1999; June 22, 2000; June 7, 2003; August 14, 2007; August 29, 2014 and February 8, 2019.*

## Alcohol and Other Drugs Education and Prevention Policy

In compliance with the federal government's Drug Free Schools & Communities Act, there are community standards and potential consequences at the Colorado School of Mines pertaining to the illegal use of alcohol or drugs. The unlawful possession, use, or distribution of illicit drugs and the unlawful or unauthorized use of alcohol by employees and students at Mines will result in disciplinary action consistent with School policies, and local, state, and federal laws.

While Colorado's Constitution allows for specific legal use, possession, and growing of marijuana under certain circumstances, because of Mines' status as a federal contractor and grant recipient and because marijuana use is still prohibited under federal law, the use, possession, and growing of marijuana on campus is prohibited. Student use of alcohol and other drugs (including marijuana) that results in an impaired ability to perform academically, or behavior that violates the Code of Conduct constitutes a violation of this policy.

For more information, or for further policy details, please see the Alcohol and Other Drugs Education and Prevention Policy and the Colorado Drug Law Summary in the Policy Library, student section (http://inside.mines.edu/POGO-Student/). Also see the Residence Life Policies (https://www.mines.edu/residence-life/) and the Annual Campus Security and Fire Safety Report (http://publicsafety.mines.edu/) for more on programming and requirements.

## Electronic Communications (E-mail) Policy

**1.0 BACKGROUND AND PURPOSE**

Communication to students at the Colorado School of Mines (Mines) is an important element of the official business of the university. It is vital that Mines have an efficient and workable means of getting important and timely information to students. Examples of communications that require timely distribution include information from Fiscal Services, the Registrar's Office, or other offices on campus that need to deliver official and time-sensitive information to students. (Please note that emergency communications may occur in various forms based on the specific circumstances).

Electronic communication through email and Trailhead Portal announcements provides a rapid, efficient, and effective form of communication. Reliance on electronic communication has become the accepted norm within the Mines community. Additionally, utilizing electronic communications is consistent with encouraging a more environmentally-conscious means of doing business and encouraging continued stewardship of scarce resources. Because of the wide-spread use and acceptance of electronic communication, Mines is adopting the following policy regarding electronic communications with students.

**2.0 POLICY**

It is the policy of the Colorado School of Mines that official university-related communications with students will be sent via Mines' internal email system or via campus or targeted Trailhead announcements. All students will be assigned a Mines email address and are expected to periodically check their Mines assigned email as well as their Trailhead portal page. It is also expected that email sent to students will be read in a timely manner. Communications sent via email to students will be considered to have been received and read by the intended recipients.

*For a complete policy statement and associated procedures please see the* policy website *(*https://inside.mines.edu/POGO-Policies-Governance/*),* information technology section. ***The policy website shall be considered the official & controlling Mines' policy.*** Nothing in the procedures should be construed as prohibiting university-related communications being sent via traditional means. Use of paper-based communication may be necessary under certain circumstances or may be more appropriate to certain circumstances. Examples of such communications could include, but not be limited to disciplinary notices, fiscal services communications, graduation information and so forth.

Questions about this policy may be directed to either of the following: Registrar's Office (https://www.mines.edu/registrar/) @ 303-273-3200 or registrar@mines.edu; or

Computing, Communications & Information Technologies (http://ccit.mines.edu/) (CCIT) @ 303-273-3431 or complete a request form at the Mines Help Center (http://helpdesk.mines.edu/).

## Student Complaint Process

Students are consumers of services offered as part of their academic and co-curricular experience at the Colorado School of Mines. If a student needs to make a complaint, specific or general, about their experience at Mines, he or she should contact the Office of the Dean of Students at 303-273-3288. If the issue is related to discrimination, sexual harassment, or sexual violence, there are specific procedures that will be followed (these are noted and linked in this section or contact the Director, Title IX & Equity, 303-273-2558. Additional contacts listed in the Title IX section below.) For all other concerns, the student should begin with the Dean's Office if interested in making any complaint. All complaints, as well as the interests of all involved parties, will be considered with fairness, impartiality, and promptness while a complaint is being researched and/or investigated by the School.

## Access to Student Records

Students at the Colorado School of Mines are protected by the Family Educational Rights and Privacy Act of 1974, as amended. This Act was designed to protect the privacy of education records, to establish the right of students to inspect and review their education records, and to provide guidelines for the correction of inaccurate or misleading data through informal and formal hearings. Students also have the right to file complaints with The Family Educational Rights and Privacy Act Office (FERPA) concerning alleged failures by the institution to comply with the Act. Copies of local policy can be found in the Registrar’s Office. Contact information for FERPA complaints:

Family Policy Compliance Office

U.S. Department of Education
400 Maryland Avenue, SW
Washington, D. C. 20202-4605

**Directory Information.** The School maintains lists of information which may be considered directory information as defined by the regulations. This information includes name, current and permanent addresses and phone numbers, date of birth, major field of study, dates of attendance, part or full-time status, degrees awarded, last school attended, participation in officially recognized activities and sports, class, academic honors, university email address, and photo including student ID picture. Students who desire that this information not be printed or released must so inform the Registrar before the end of the first two weeks of the fall semester for which the student is registered. Information will be withheld for the entire academic year unless the student changes this request. The student's signature is required to make any changes for the current academic year. The request must be renewed each fall term for the upcoming year. The following student records are maintained by Colorado School of Mines at the various offices listed below:

1. General Records: Registrar and Graduate Dean
2. Transcript of Grades: Registrar
3. Computer Grade Lists: Registrar
4. Encumbrance List: Controller and Registrar
5. Academic Probation/Suspension List: Graduate Dean
6. Advisor File: Academic Advisor
7. Option/Advisor/Enrolled/ Minority/Foreign List: Registrar, Dean of Students, and Graduate Dean
8. Externally Generated SAT/GRE Score Lists: Graduate Dean
9. Financial Aid File: Financial Aid (closed records)
10. Medical History File: School Physician (closed records)

**Student Access to Records.** The graduate student wishing access to his or her educational records will make a written request to the Graduate Dean. This request will include the student's name, date of request and type of record to be reviewed. It will be the responsibility of the Dean to arrange a mutually satisfactory time for review. This time will be as soon as practical but is not to be later than 30 business days from receipt of the request. The record will be reviewed in the presence of the Dean or designated representative. If the record involves a list including other students, steps will be taken to preclude the viewing of the other student name and information.

**Challenge of the Record.** If the student wishes to challenge any part of the record, the Dean will be so notified in writing. The Dean may then

1. remove and destroy the disputed document, or
2. inform the student that it is his decision that the document represents a necessary part of the record; and, if the student wishes to appeal,
3. convene a meeting of the student and the document originator (if reasonably available) in the presence of the Executive Vice President for Academic Affairs as mediator, whose decision will be final.

**Destruction of Records.** Records may be destroyed at any time by the responsible official if not otherwise precluded by law except that no record may be destroyed between the dates of access request and the viewing of the record. If during the viewing of the record any item is in dispute, it may not be destroyed.

**Access to Records by Other Parties.** Colorado School of Mines will not permit access to student records by persons outside the School except as follows:

1. In the case of open record information as specified in the section under Directory Information.
2. To those people specifically designated by the student. Examples would include request for transcript to be sent to graduate school or prospective employer.
3. Information required by a state or federal agency for the purpose of establishing eligibility for financial aid.
4. Accreditation agencies during their on-campus review.
5. In compliance with a judicial order or lawfully issued subpoena after the student has been notified of the intended compliance.
6. Any institutional information for statistical purposes which is not identifiable with a particular student.
7. In compliance with any applicable statue now in effect or later enacted. Each individual record (general, transcript, advisor, and medical) will include a log of those persons not employed by Colorado School of Mines who have requested or obtained access to the student record and the legitimate interest that the person has in making the request.

The School discloses education records without a student's prior written consent under the FERPA exception for disclosure to school officials with legitimate educational interests. A school official is a person employed by the School in an administrative, supervisory, academic or research, or support staff position (including law enforcement unit personnel and health staff); a person or company with whom the School has contracted as its agent to provide a service instead of using School employees or officials (such as an attorney, auditor, or collection agent); a person serving on the Board of Trustees; or a student serving on an official committee, such as a disciplinary or grievance committee, or assisting another school official in performing his or her tasks.

A school official has a legitimate educational interest if the official needs to review an education record in order to fulfill his or her professional responsibilities for the School.

See also FERPA (https://www.mines.edu/policy-library/wp-content/uploads/sites/87/2018/04/FERPA-Policy-2018-1.pdf) at Mines in the Registrar's pages.

## Posthumous Degree Awards

The faculty may recognize the accomplishments of students who have died while pursuing their educational goals. If it is reasonable to expect that the student would have completed his or her degree requirements, the faculty may award a Baccalaureate or Graduate Degree that is in all ways identical to the degree the student was pursuing. Alternatively, the faculty may award a Posthumous BS, MS, or PhD to commemorate students who distinguished themselves while at Mines by bringing honor to the School and its traditions.

Consideration for either of these degrees begins with a petition to the Faculty Senate from an academic department or degree granting unit. The petition should identify the degree sought. In the event that the degree-granting unit is seeking a conventional degree award, the petition should include evidence of the reasonable expectations that the student would have completed his or her degree requirements. For a Baccalaureate, such evidence could consist of, but is not limited to:

- The student was a senior in the final semester of coursework,
- The student was enrolled in courses that would have completed the degree requirements at the time of death
- The student would have passed the courses with an acceptable grade, and would likely have fulfilled the requirements of the degree.

For a Graduate Degree:

- For graduate degrees not requiring a research product, the student was enrolled in courses that would have completed the degree requirements at the time of death, would have passed the courses with an acceptable grade, and would likely have fulfilled the requirements of the degree.
- For graduate degrees requiring a research product, the student had completed all course and mastery requirements pursuant to the degree and was near completion of the dissertation or thesis, and the student's committee found the work to be substantial and worthy of the degree.

The requirement that there be a reasonable expectation of degree completion should be interpreted liberally and weight should be given to the judgment of the departmental representative(s) supporting the petition.

In the event that the degree being sought is a Posthumous BS, MS, or PhD, the petition should include evidence that the student conducted himself or herself in the best tradition of a Mines' graduate and is therefore deserving of that honor.

## Equal Opportunity, Equal Access, and Affirmative Action

The institution's Statement of Equal Opportunity and Equal Access to Educational Programs, and associated staff contacts, can be found in the Welcome Section of this Catalog as well as the on the policy website (https://inside.mines.edu/POGO-Policies-Governance/). Colorado School of Mines maintains an affirmative action plan, which is available at the Arthur Lakes Library, the Dean of Students' Office, and the Office of Human Resources.

## Title IX @ Mines

**Katie Schmalzel**, Interim Title IX Coordinator + Director, Title IX Programs
Title IX Office, 1706 Illinois Street, Golden, CO 80401
303.384.3260 | kschmalz@mines.edu

E-mail titleix@mines.edu or visit https://www.mines.edu/title-ix/ for more information.

## SpeakUP@Mines

Students and employees have an additional anonymous channel for reporting concerns through the Whistleblower Policy and the SpeakUP@Mines (http://speakup.mines.edu/) program.

## Consumer Information - Your Right to Know

As a prospective or continuing student at Colorado School of Mines, you have a right to certain information that the university is required by law to provide. Much of that information is safety related or financial in nature, but other broad categories are included such as graduation rates, athletics, and the various costs associated with attending Mines.

Current federal regulations require that institutions of higher education disclose such information and make it readily available to current and prospective students. A new provision in the Higher Education Amendments of 1998 requires institutions to provide a list of the information to which students are entitled with instructions on how they may obtain it. A paper copy of all of the information can be found in the Compliance and Policy Office in Guggenheim Hall.

More information can be found on the Financial Aid website (https://finaid.mines.edu/).

# Directory of the School

# Emeriti

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# Coaches/Athletics Faculty

Please refer to the Mines' Athletics Web Site (https://minesathletics.com/staff-directory/) for all current Faculty information.

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