2015-16

COLORADO SCHOOL OF MINES RESEARCH

Modern Metal

Collaborative Advanced Steel Processing and Products Research Center advances methodologies, alloying strategies and production processes | **PAGE 30**

A prof's path from chemical to biological engineering | **PAGE 28**

Corporate responsibility and community relations | **PAGE 38**

Transitions

COLORADOSCHOOLOFMINES

We explore "transitions" in this issue of the Colorado School of Mines research magazine — interestingly, the theme also fits for me as I assume the role of facilitator of the Mines research enterprise — a role previously held by John Poate, retired vice president for research and technology transfer. (See Dr. Poate's farewell column on page 42.)

Colorado School of Mines has prospered in the research arena during John's tenure, and all signs suggest this positive trajectory will continue. Clearly, our resourceful, dedicated faculty are leading the charge. These individuals, in concert with their grad students, postdocs and undergrads, have identified multiple ways to advance the Mines mission of "education and research in engineering and science to solve the world's challenges related to the earth, energy and the environment."

IN THIS ISSUE

The three feature articles in this issue touch on a few examples of our researchers' significant efforts. These articles reflect both the diversity of research activities on campus as well as the interdisciplinary nature of many projects.

- The research within the Advanced Steel Processing and Products Research Center exemplifies one of the traditional strengths of Mines (page 30). This entity is recognized worldwide for its excellence in pushing technological frontiers.
- We are all aware the combination of horizontal drilling and hydraulic fracturing has revolutionized oil and gas production. The story on geothermal energy (page 34) describes the extension of those technologies to develop new approaches to harnessing this renewable resource.
- On the policy front, Mines researchers focused on corporate and social responsibility and energy development are investigating methods to establish best practices to meet the needs of both businesses and communities (page 38).

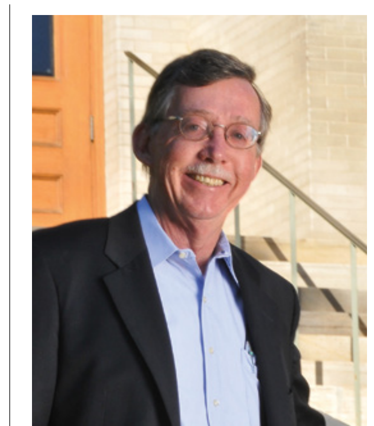
MAJOR INITIATIVES

Another manifestation of the impact of Mines researchers is their participation in major manufacturing initiatives. One such project is the Institute for Advanced Composite Manufacturing Innovation (IACMI) that is focused on advanced manufacturing using state-of-the-art composite materials. These materials include carbon fiber, glass fiber and hybrid composites. The application areas of primary interest are wind turbines, storage tanks for natural gas powered vehicles, and high mileage, lightweight automobiles. Within the next decade, IACMI plans to lower the overall manufacturing costs of advanced composites by 50 percent, reduce energy use by 75 percent and increase the ability to recycle composites by more than 95 percent. (More on page 9.)

Mines is also a key participant in a new manufacturing institute focused on lightweight materials. Lightweight Innovations for Tomorrow (LIFT) is one of the initial five institutes funded by the U.S. government with the goal to maintain America's manufacturing leadership and accelerate technologies. Development of lightweight materials and technologies are critical to industries for a variety of applications including the advancement of more fuel-efficient transportation vehicles, and production of lighter weight armor for land and sea-based military equipment. The institute will work primarily with aluminum, magnesium, titanium and advanced high-strength steel alloys. Inclusion of Mines in the institute was natural due to the strength of the industry-based programs on advanced metals at the university.

We continue to build state-of-the-art labs at Mines. A recent example is construction of a 2,200-square-foot radiochemistry lab. This will allow Mines faculty and students to work with some of the rarest elements at the edge of the periodic table. Their goal is to solve crucial energy and environmental problems that face the world today — like the 70,000 tons of highly radioactive waste from nuclear reactors that is temporarily stored at sites around the country.

Anthony Dean
Senior Vice President for Research and Technology Transfer



Anthony Dean was appointed senior vice president for research and technology transfer at Colorado School of Mines in January 2015. He was named vice president for research in October 2014 after serving as dean of the College of Applied Science and Engineering from 2012 to 2014. Prior, he served as the W. K. Coors Distinguished Professor in the Mines Department of Chemical and Biological Engineering.

Previously, Dean taught for nine years in the Chemistry Department at the University of Missouri-Columbia. He then moved to the Corporate Research Labs of Exxon Research and Engineering where he formed a research group to develop quantitative kinetic mechanisms to describe processes involving free radical reactions.

In 2000, he joined the Mines community, where he is still active in research. His group's research efforts focus on using electronic structure calculations to develop rate rules for free radical reactions and the use of these rules to develop quantitative kinetic mechanisms. These mechanisms can then be applied to a variety of systems, ranging from the impact of the combustion of alternative fuels to biocorrosion to biomass pyrolysis.

In 2008, he received the Dean's Excellence Award at Mines. In 2012, he received the Colorado Section Award from the American Chemical Society.

He received his bachelor's degree in chemistry from Spring Hill College and his master's degree and PhD in physical chemistry from Harvard University.

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RESEARCH

On the cover: Graduate student Blake Whitley prepares a Gleeble thermomechanical rolling simulation in Mines' Advanced Steel Processing and Products Research Center.

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

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Features

COLORADO SCHOOL OF MINES

*By the Numbers**

**2014-15 academic year*

Enrollment

4,383 UNDERGRADUATE	1,290 GRADUATE

Total degree-seeking: ***5,673***

Freshman retention	Four-year graduation rate	Six-year graduation rate
94%	46%	76%
2013 cohort	2008 cohort	2010 cohort

99% employed or in graduate school within 1 year of graduation

Avg starting salary: **$67,540**

College of Engineering & Computational Sciences
2,137

College of Applied Sciences & Engineering
1,417

College of Earth Resource Science & Engineering
1,728

Largest **Society of Women Engineers** student chapter in the nation

Research

Average sponsored research awards total and by sector. *(FY15)*

Total $63.9 million

- **Federal $34.4**
- **State $1.7**
- **Private $27.8**

Private Support

Transforming Lives Campaign

Goal: $350 million

Raised: $274 million *(as of 6/10/15)*

FY15 fundraising results: **$40.7 million**

Endowment: **$270 million** *(as of 6/10/15)*

Miscellaneous facts:

36 – Student selectivity rank per U.S. News Best Colleges report

718 – Average GRE quantitative score

1327 – Average SAT

4,602 On-campus interviews conducted

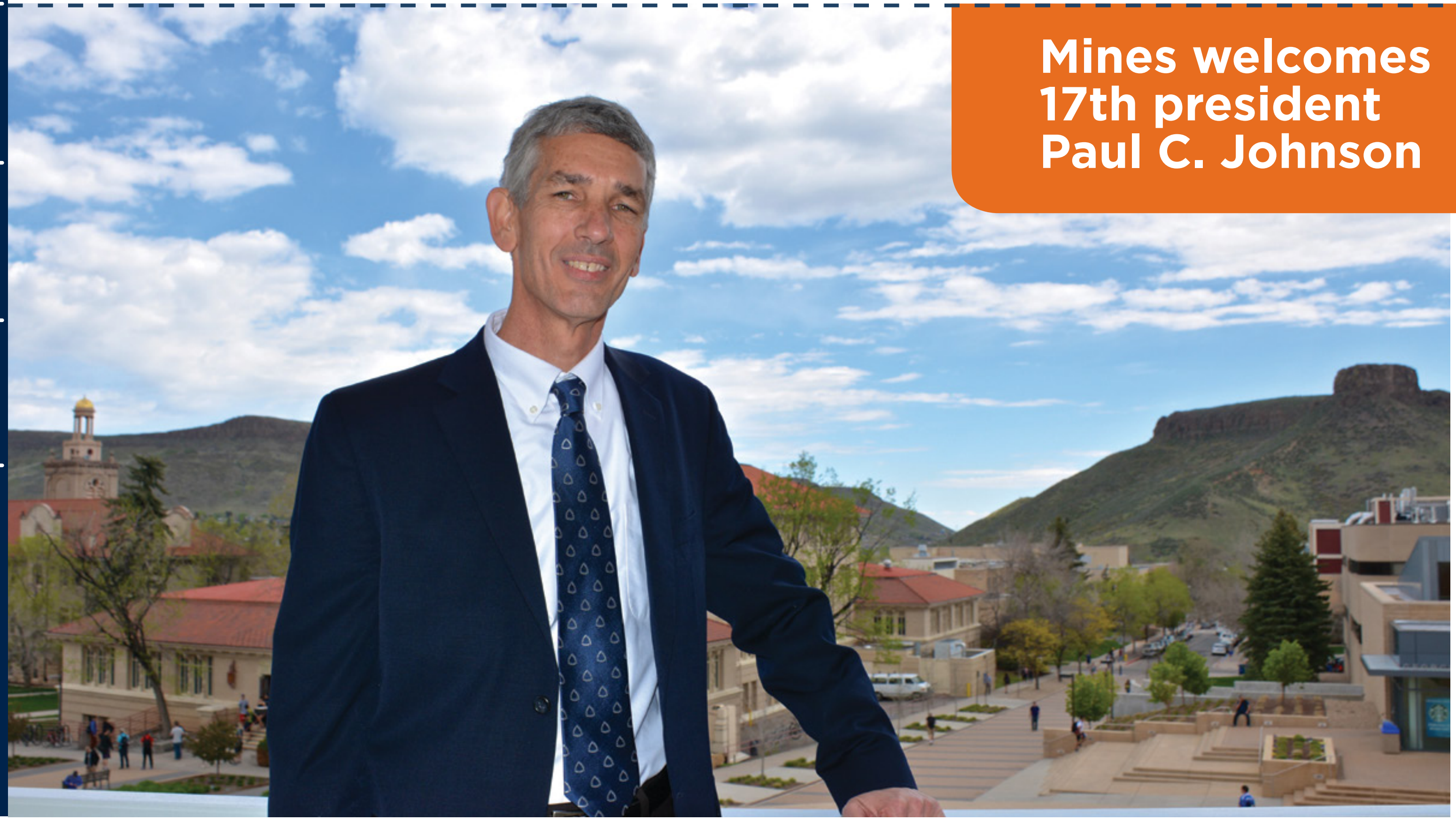
23 Current Mines faculty who have received NSF Early CAREER awards

36 Named faculty positions

Presidential Early CAREER Award for Scientists and Engineers winners on Mines faculty:

Ryan O'Hayre
2009

Moises Carreon
2013



Mines welcomes 17th president Paul C. Johnson

Paul Johnson comes to Mines from Arizona State University (ASU) where he served as dean and executive dean of the Ira A. Fulton Schools of Engineering since 2006 and was a professor in the School of Sustainable Engineering and Built Environment. He joined the ASU faculty in 1994 and went on to serve as the university's associate vice president for research and the Fulton Schools' associate dean for research. Before joining ASU, Johnson worked as a senior research engineer at the Shell Oil/Shell Chemical Westhollow Technology Center.

Johnson is internationally recognized for his expertise in soil and groundwater remediation and risk assessment. He has co-authored 12 U.S. patents and has received awards recognizing the impact of his research and contributions to the groundwater profession including the National Ground Water Association's Keith E. Anderson Award (2010) and the Lifetime Award in Remediation sponsored by Brown and Caldwell (2014). His research group has received Project of the Year Awards from both the Environmental Security Technology Certification and Strategic Environmental Research and Development Programs, which are given by the U.S. Department of Defense in partnership with the Environmental Protection Agency.

Johnson served on the National Research Council Committee on Future Options of the Nation's Subsurface Remediation Effort and as the editor for the National Ground Water Association's journal, *Ground Water Monitoring and Remediation.*

He earned his bachelor's degree in chemical engineering from the University of California-Davis, and his master's and doctoral degrees in chemical engineering from Princeton University.

"I am excited and honored to be named Mines' 17th president. I have received and continue to receive emails from connections to Mines that I did not know existed. Mines' far-reaching, engaged, and supportive network is impressive. From on-campus meetings it is clear that Mines has the components and drive to become the premier engineering and applied science university. I look forward to working with the students, staff, faculty, alumni and Mines' global network to achieve that aspiration."

CAMPUS

Award-winning architects chosen to design CoorsTek Center for Applied Science and Engineering

Internationally renowned architecture firm Bohlin Cywinski Jackson, in partnership with Denver-based Anderson Mason Dale Architects, has been selected to design the new CoorsTek Center for Applied Science and Engineering at Colorado School of Mines.

The modern, $50 million centralized teaching and research space will serve as an integral campus landmark located on the site of the current physics building, Meyer Hall, at 15th and Arapahoe streets. The nearly 100,000-square-foot building will feature forward-thinking design with flexible lab space and customized, technologically advanced classrooms to foster interactive, hands-on learning.

Bohlin Cywinski Jackson has designed notable buildings on many college campuses around the country and is also widely known for designing the iconic Apple store on Fifth Avenue in New York City and the Pixar Animation Studios in California. Anderson Mason Dale has designed several notable buildings on Mines' campus and its body of higher education work is well known, particularly in the Western United States. The two firms recently collaborated on the design of Marquez Hall at Mines.

Last fall, Mines announced the nearly $27 million commitment by CoorsTek and the Coors family in conjunction with $14.6 million in capital construction funding from the state of Colorado for the new building. The private investment — the largest of its kind in Mines' 140-year history — is also funding the CoorsTek Research Fellows Program and a range of high-tech equipment purchases, including one of the most advanced electron microscopes in the United States.

Construction is slated to begin in 2016.

RESEARCH

Advancing composites

The U.S. Department of Energy and a consortium of 122 companies, nonprofits, and universities including Colorado School of Mines, will invest more than $250 million — $70 million in federal funds and more than $180 million in non-federal matching funds — to launch the Institute for Advanced Composites Manufacturing Innovation (IACMI).

Led by the University of Tennessee, IACMI is developing new low-cost, high-speed, and efficient manufacturing and recycling process technologies that will promote widespread use of advanced fiber-reinforced polymer composites in wind turbine, automotive, and compressed natural gas applications.

John Dorgan, professor of chemical engineering and faculty participant in the Materials Science Program at Mines, is creating new materials for wind turbine blade manufacturing. Dorgan's research focuses on specialized thermoplastic technology utilizing ring-opening polymerization. Mines will receive $1 million per year for the next five years.

"Thermoplastic use reduces weight and costs, enables the production of segmented blades, and facilitates recycling of the plastic composites at the end of their service life; it creates additional manufacturing jobs in the conversion of the reclaimed materials and significantly improves important sustainability metrics," Dorgan said.

Mines is collaborating with partners Johns Mansville, the National Renewable Energy Laboratory (NREL), Colorado State University and others on an initial project, "Thermoplastic Infusion – Enabling Recycling, Reducing Costs, Enhancing Sustainability." Dorgan has been awarded a collaborative appointment at NREL due to his extensive interactions with the laboratory.

CAMPUS

Mines introduces Center for Innovative Teaching & Learning

The Center for Innovative Teaching & Learning (CITL) is part of Mines' Strategic Plan initiative to further the school's STEM reputation, expand research opportunities and increase graduation rates.

Led by Sam Spiegel, the center aims to enhance faculty connections, provide resources and form an active learning community at Mines.

Prior to joining Mines, Spiegel served as chair of the Disciplinary Literacy in Science Team at the Institute for Learning and associate director for the Swanson School of Engineering's Engineering Education Research Center at the University of Pittsburgh. He was the founding director of the Center for Integrating Research & Learning at the National High Magnetic Field Laboratory at Florida State University, a center that has been recognized as one of the leading National Science Foundation Laboratories for activities to promote STEM education.

"The pieces that get me excited are real and rich conversations about teaching and learning," said Spiegel. "I am looking forward to getting involved in the design aspects and supporting faculty and students in changing, growing and enhancing their experiences at Mines."

The CITL offers resources in coaching, course review, curricula design, grant support, learning communities, teaching observations and teaching professional development. Visit the CITL's website for information on pedagogy seminars and updates at citl.mines.edu.

FACULTY AWARDS

Three Mines faculty members receive 2015 NSF CAREER awards

The NSF CAREER award is the most prestigious award in support of junior faculty who exemplify the role of teacher-scholars through outstanding research, excellent education and the integration of education and research within the context of the mission of their organizations.

Three Mines professors received the award in 2015:

• Ning Wu, Department of Chemical and Biological Engineering assistant professor, has received the award for his research, "In- and Out-of-Equilibrium Behavior of Colloidal Clusters with Broken Symmetries."

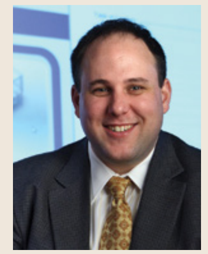
"Colloidal dispersions play an important role in materials processing for industries ranging from electronics to pharmaceuticals. When colloidal particles are organized into arrays and other structures, the resulting materials can exhibit optical and electrical properties that are not found in natural materials. Therefore, colloids serve as building blocks for fabricating advanced functional materials," Wu's abstract states.

Results from the project will provide fundamental knowledge that scientists and engineers can use to develop materials and devices, such as new sensors or coatings with controlled optical properties.

• Kathleen Smits, Department of Civil and Environmental Engineering assistant professor, received support for "Advancing the Science and Education of Land Surface-atmosphere Interactions: Interweaving Multiscale Experimental and Modeling Approaches for Land Surface Models (LSM) and Experiential Learning."

LSMs are numerical models used to simulate processes at the surface and the subsurface and their feedbacks to the atmosphere. They are used in part for climate change predictions. The goal of Smits' research is to advance the understanding and modeling of mass and energy exchange at the land-atmosphere interface over a wide range of scales, and ultimately improve LSMs that are utilized in global climate prediction.

The study will create an educational framework for engaging minority middle school students in STEM fields. Focusing on the integrating theme of water and climate, this research will help students make the link between STEM they learn in the classroom and environmental water resource problems in their own backyards, motivating and preparing students to pursue college studies and ultimately careers in STEM fields.



• Aaron Stebner, Department of Mechanical Engineering assistant professor, was awarded for, "In-situ Advancements for Study of Multi-axial Micromechanics of Solid Materials."

The project will examine the mechanics of the microscale level deformation of metals through advanced experimental mechanics and analysis, including novel in-situ X-ray diffraction experiments. The research will contribute to national Materials Genome and Advanced Manufacturing Initiatives.

Stebner's work will help explore new territory in the study of micromechanics phase transformation in shape memory alloys and stainless steels.

As many as 23 Mines faculty have received CAREER awards since 2000. Winners from 2010-15 pose with university leadership following a luncheon in their honor. From left, Dean Kevin Moore, Dean Michael Kaufman, Christian Ciobanu (2010), Senior Vice President for Research and Technology Transfer Tony Dean, Sumit Agrawal (2010), Provost Terry Parker, Michael Wakin (2012), Josh Scharp (2012), Ning Wu (2014), Kip Findley (2010), Mines President Emeritus Bill Scoggins, Dean Ramona Graves and Aaron Stebner (2015). Not pictured: Kate Smits (2015), Keith Neeves (2014), Corrine Packard (2014), Jenifer Braley (2013 & 2014), Moises Carreon (2014), Yvette Kuiper (2013), Gavin Hayes (2013), Zhigang Wu (2011), Tony Petrella (2010) and Ryan O'Hayre (2010).

RESEARCH

Off-the-Grid: Fuel cells that could power your home

A team of two metallurgical and materials engineering professors and three mechanical engineering professors at Colorado School of Mines has been awarded $1 million through Advanced Research Projects Agency-Energy's Reliable Electricity Based on Electrochemical Systems Program to develop high-efficiency, medium-temperature fuel cells that can produce electricity from natural gases.

"Imagine you could replace the water heater in your home with a similarly-sized fuel cell unit that could also produce the electricity for your home," Metallurgical and Materials Professor Ryan O'Hayre said. "You wouldn't need the electric grid anymore. This would be great for remote cabins, but also for people that want to get off-the-grid.

O'Hayre, and professors Neal Sullivan, Robert Braun, Jianhua Tong and Sandrine Ricote, are working to address three opportunities for this new fuel cell technology: lowering the cost and temperature, and designing a fuel cell that can operate on a variety of fuels.

"I am hoping for the day when I can buy a natural-gas powered fuel cell for my home that could provide both my electricity and hot water with an overall combined efficiency of more than 80 percent," O'Hayre said. "I am optimistic that this could happen before my baby daughter goes to college."

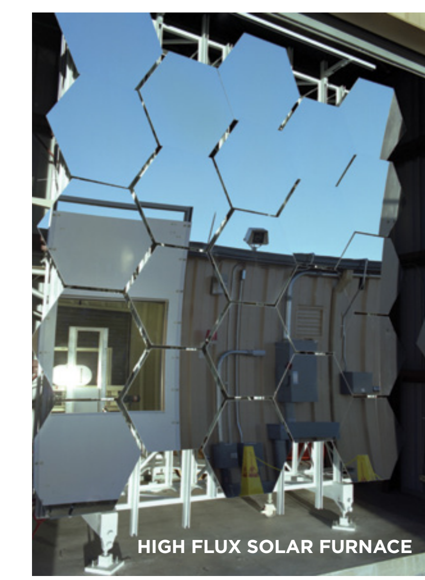
The team is working on demonstrating feasibility in a single-cell fuel cell device to further scale it to a larger size with multiple fuel cells connected together to produce a greater amount of power.

RESEARCH

Engineering new solar energy storage systems

As part of the Department of Energy's SunShot Initiative to drive down the cost of solar-based power generation, Colorado School of Mines, in partnership with Abengoa and the National Renewable Energy Laboratory, received a two-year, $1 million award to develop a new method for storing solar energy.

The SunShot Initiative funds six awardees, for $10 million total, for the "Concentrating Solar Power: Efficiently Leveraging Equilibrium Mechanisms for Engineering New Thermochemical Storage (CSP: ELEMENTS)" funding program. It supports development of thermochemical energy storage systems that can validate a cost of less than or equal to $15 per kilowatt-hour-thermal and operate at temperatures greater than or equal to 650 degrees Celsius (1202 degrees Fahrenheit).



Courtesy of NREL

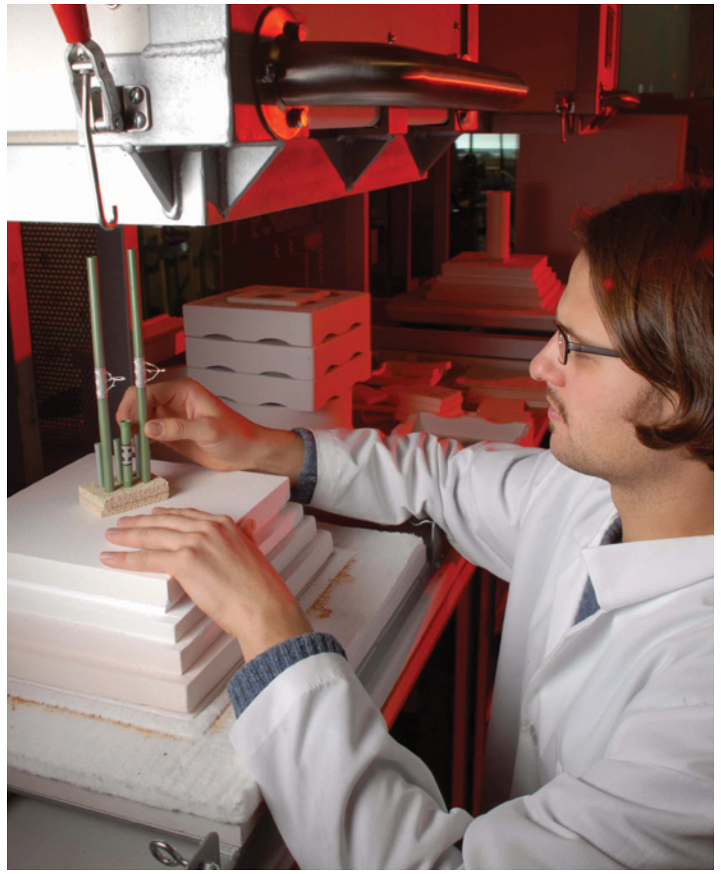
Greg Jackson, head of the Department of Mechanical Engineering at Mines, is leading the project, exploring the use of highly reducible oxides (perovskites from earth abundant elements) to store concentrated solar energy both in heat and chemical bonds. The technology has the potential to allow concentrated solar power plants to utilize stored energy for continued plant operation through the night or other periods of low solar insolation.

Jackson is joined by Mines mechanical engineering colleagues Robert Braun and Robert Kee, as well as Ryan O'Hayre from the Department of Metallurgical and Materials Engineering, to work on materials development and system design of the novel energy storage concept. Abengoa's Christina Lopez is leading efforts on systems integration and techno-economic analysis, focusing on the potential for commercializing this technology in future solar plant projects.

Zhiwen Ma at NREL is leading an effort with team partners to adapt NREL's near blackbody solar receiver design to operate as a reactor for capturing the sun's energy as storable thermochemical energy in perovskite particles. NREL is using its high flux solar furnace to verify the solar energy conversion and the solar thermal/chemical processes.

RESEARCH

Driving options: fuel cell cars



The Department of Energy announced a $4.5 million investment in two projects — led by Colorado School of Mines and Minnesota-based 3M — to lower the cost, improve the durability and increase the efficiency of next-generation fuel cell systems.

Mines will receive $1.5 million to develop advanced hybrid membranes for cutting-edge, next-generation fuel cells that are simpler, more affordable and able to operate at higher temperatures. Professor of Chemical and Biological Engineering Andrew Herring is leading the project at Mines, with partners at NREL, Nissan USA and 3M.

"This project began as a basic science effort, but we now have the opportunity to demonstrate the materials in actual fuel cells. If successful, these fuel cells will help drive down the cost and increase the efficiency and durability of the fuel cell cars that are currently being commercialized," Herring said.

3M will receive $3 million to focus on developing innovative fuel cell membranes with improved durability and performance using processes, that are easily scalable to commercial size.

"Fuel cell technologies have an important role to play in diversifying America's transportation sector, reducing our dependence on foreign oil, and curbing harmful carbon pollution," said Assistant Secretary for Energy Efficiency and Renewable Energy David Danielson. "By partnering with private industry and universities, we can help advance affordable fuel cell technologies that save consumers money and give drivers more options while creating jobs in this growing global industry."

RESEARCH

Making next gen solar affordable, more efficient

Energy Secretary Ernest Moniz announced more than $53 million for 40 innovative solar energy research and development projects, including one competitive award to Colorado School of Mines and the Energy Department's National Renewable Energy Laboratory (NREL), to develop low cost, extremely high efficiency solar cells. This project supports the goals of the Energy Department's SunShot Initiative to drive down the cost of solar energy and move innovative ideas to the market more quickly.

Assistant Professor Corinne Packard, of the Mines Metallurgical and Materials Engineering Department, is working with NREL researchers Aaron Ptak and David Young on a project to develop a InGaAsP/Si (indium gallium arsenide phosphide/silicon) tandem photovoltaic technology that leverages extremely high efficiency devices and low-cost, high-throughput methods to meet and exceed SunShot cost targets.

RESEARCH

Multidisciplinary Mines team publishes book on pore scale phenomena

"Pore Scale Phenomena: Frontiers in Energy and Environment," a book edited by Colorado School of Mines faculty devoted to understanding the physical and chemical properties of pore scale phenomena, has recently been published by *World Scientific*.

The publisher notes, "the book provides, for the first time, a comprehensive overview of the fascinating interrelationship between engineering and science."

Edited by Emeritus Vice President for Research John Poate, Civil and Environmental Engineering Professor Tissa Illangasekare, Petroleum Engineering Professor Hossein Kazemi, and Mechanical Engineering Professor Robert Kee with assistance from Assistant Professor of Petroleum Engineering Luis Zerpa, the volume is one of the first multidisciplinary books published on the subject. It covers the relationship between oil and gas reservoirs; hydrogeology; and materials science, energy, devices and biology.

In his overview, Poate notes, "The properties of these phenomena range across length scales from the atomic to the geographic and have large economic and societal implications. The genesis of this endeavor rose through a series of meetings at Colorado School of Mines where we realized that the school had a critical mass of faculty addressing key pore scale research issues ... Mines has a proud record in applied research and engineering from its founding days and its impact on the mining industry in the U.S. and the world."

Illangasekare, who holds the AMAX Distinguished Chair and is president-elect of the International Society of Porous Media (InterPore), past editor of *Water Resources Research*, past co-editor of *Vadose Zone Journal* and the 2012 chair of the Gordon Research Conference on Flow and Transport in Permeable Media, said the diverse research team hopes the book will be a catalyst for ideas to come.

"It is our hope this book will help lead to new discoveries in both porous media sciences and their applications," Illangasekare said. "This book is an attempt to illustrate some of the commonalities in the fundamentals of various porous media phenomena across disciplines to develop new insights in cross-disciplinary approaches to address some of the emerging and challenging problems in energy development, water sustainability, human health, materials and the protection of the environment."

Kazemi, who holds the Chesebro' Distingusihed Chair in Petroleum Engineering and who co-directs the Marathon Center of Excellence for Reservoir Studies, said his work on this project helped him understand that pores are abundant in the common materials that encompass our lives.

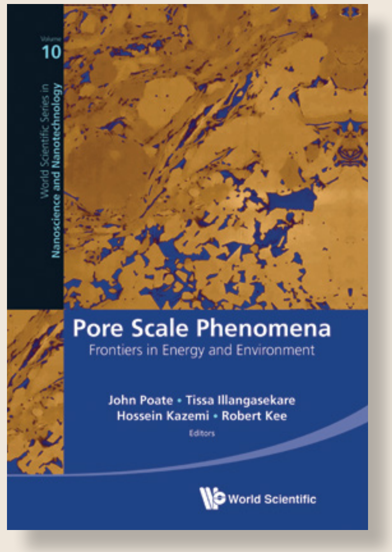
"My involvement also sharpened my view of pore-scale flow and mass transport, and the realization that much of the research work conducted in other disciplines could be of great benefit to the research on subsurface flow. The book also introduced me to many wonderful scientists and engineers," Kazemi said.

Recognizing and learning about synergies between leading research in geosciences and electrochemical energy-conversion technology was particularly interesting to Kee, who holds the George R. Brown Distinguished Chair in Mechanical Engineering.

"Direct collaborations between researchers in the earth sciences and those in advanced energy technologies is relatively uncommon. However, it turns out that we develop and apply similar theories and approaches to understand transport and chemistry in porous rock structures as we do to represent transport and chemistry in fuel-cell and battery electrodes. Hopefully, this book will help to facilitate fruitful interactions and cross-fertilizations between heretofore diverse communities, both on campus and in broader scientific realms," said Kee.

For Zerpa, who was involved in the technical edition, layout design and typesetting of the book with help from graduate students Jeff Brown and Giovanny Grasso, the book project was a valuable collaborative experience.

"During my first year at Mines I was asked by Dr. Kazemi to write a chapter for the book about natural gas hydrates occurrence in nature – basically covering the formation and dissociation of hydrates in porous media from experimental and modeling perspectives. I wrote this chapter in collaboration with Chemical and Biological Engineering Professor Carolyn Koh, director of the Center for Hydrate Research. My chapter is an example of the cross-collaboration between colleges and departments that happens at Mines on a daily basis," Zerpa said.



"This volume is a remarkable addtion to the *World Scientific* series in nanoscience and nanotechology, and it comes at a most propitious time. Hydraulic fracturing is fundamentally altering the global energy outlook, and this book offers an unprecendented overview of the physics, chemistry and mechanics of the porous media that contain and eventually yield new gas and oil. It also illustrates how the study of this techology needs to bridge the length scales: from macroscopic geologic formations down to the nanoscale of the pores."

—Frans Spaepen, John C. and Helen F. Franklin Professor of Applied Physics, Harvard University

FACULTY AWARDS

Three Mines physicists serve as prestigious journal editors

The American Institute of Physics (AIP) publishes 17 journals. Of those, three operate with Mines physicists in the editor's chair. Professor Reuben Collins is editor-in-chief of *Applied Physics Letters,* Professor Craig Taylor is editor-in-chief of the *Journal of Renewable and Sustainable Energy* and Emeritus Senior Vice President John Poate is editor-in-chief of *Applied Physics Reviews.*

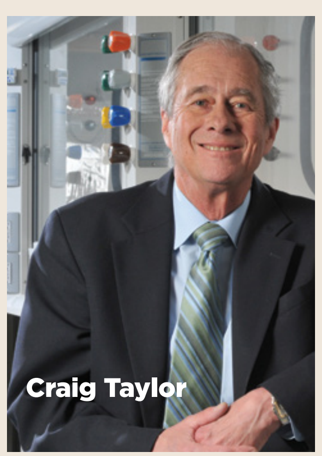
"Having three editors is extraordinary and speaks highly of the quality of the faculty and students at Mines and the positive trajectory of the campus in terms of its reputation in significant, scientific research," said Jeff Squier, head of the Mines Physics Department.

To become an editor you must have a reputation of excellence at the international level, Squier said, as well as an excellent track record in service to the scientific community and a knowledge base of the scientific field that is broader than your specialty.

"Craig Taylor, Reuben Collins and John Poate exemplify these qualities and more," Squier said.

Collins was appointed editor of *Applied Physics Letters* in fall of 2014. The Journal offers "prompt publication of new experimental and theoretical papers bearing on applications of physics phenomena to all branches of science, engineering, and modern technology."

Collins earned his PhD in applied physics at the California Institute of Technology in 1985. For the next 10 years he rose through the ranks at the IBM T.J. Watson Research Center before joining the Mines faculty in 1994. In addition to his role as professor of physics, he serves as associate director of the Renewable Energy Materials Research Science and Engineering Center (REMRSEC). He is a Fellow of the American Physical Society, holds four patents and has published more than 130 scientific articles.

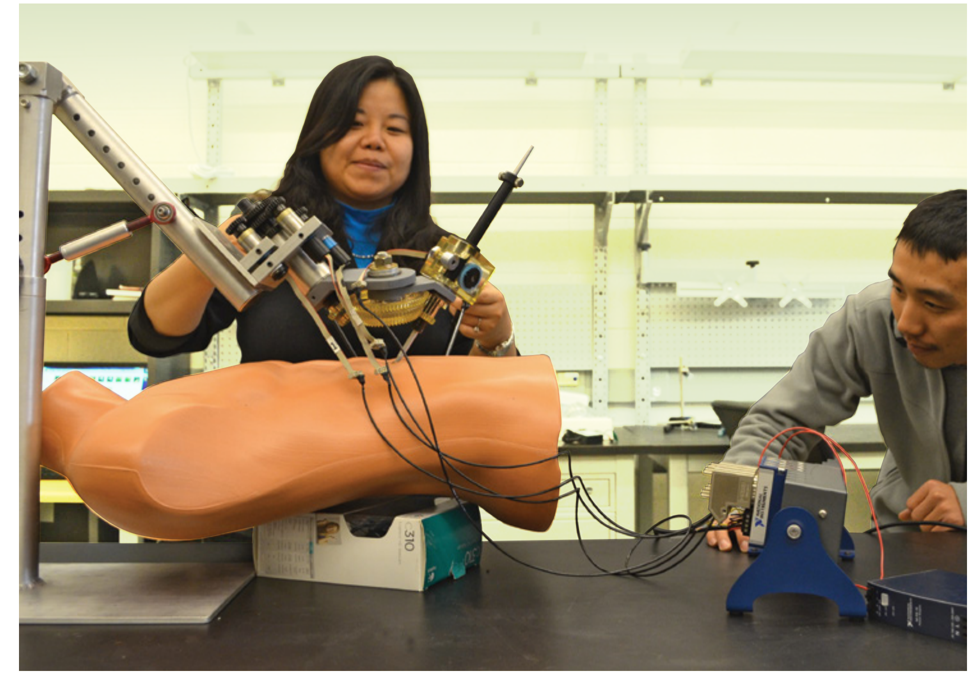


Taylor has been editing the *Journal of Renewable and Sustainable Energy* since 2008. He shares the duties with co-editor John Turner, from the Energy Department's National Renewable Energy Laboratory (NREL). It is an interdisciplinary journal covering all areas of renewable or sustainable energy that are applicable to the physical sciences and engineering communities. The journal, which is six years old, covers the widest range of topics of any AIP journal. They include bioenergy, geothermal energy, marine and hydroelectric energy, solar energy, wind energy and more.

Taylor received his bachelor's degree from Carleton College and his PhD from Brown University. He has written more than 400 scientific papers including book chapters and review articles. He is a fellow of the American Physical Society and member of the American Association for the Advancement of Science, the Materials Research Society and the American Association of Physics Teachers. In addition to his role as professor of physics, he serves as REMRSEC director.

Poate has been editor-in-chief at *Applied Physics Reviews* since 1984. He co-edits with Bill Appleton, of the University of Florida. The publication features reviews of important and current topics of experimental or theoretical research in applied physics and applications of physics to other branches of science and engineering. These articles vary from comprehensive reviews covering established areas to concise reviews covering new and emerging areas of science.

Poate, who retired from Mines in 2014 after serving as vice president of research and technology transfer since 2006, earned his PhD in nuclear physics from the Australian National University. He later headed the Silicon Processing Research Department at Bell Laboratories and is former dean of the College of Science and Liberal Arts at New Jersey Institute of Technology. He is a fellow of the American Physical Society and the Materials Research Society and served as president of the Materials Research Society and chair of the NATO Physical Sciences and Engineering Panel. Poate chairs the Lawrence Livermore National Laboratory review committees and is on the board of the NREL.



RESEARCH

Eye tracking system may modernize robotic surgeries

Mechanical Engineering Assistant Professor Xiaoli Zhang and graduate student Songpo Li have developed a gaze-contingent-controlled robotic laparoscope system that can help surgeons better perform laparoscopic surgery.

Unlike open surgery, laparoscopic surgeries reduce scarring, lessen blood loss, shorten recovery times and decrease post-operative pain. But due to limitations of holding and positioning the laparoscope, surgeons struggle with physiologic tremors, fatigue and the fulcrum effect.

Zhang and Li's attention-aware robotic laparoscope aims to eliminate some of these physical and mental burdens.

"The robot arm holds the camera so the surgeon doesn't have to," Zhang said, noting that the camera is controlled effortlessly. "Wherever you look, the camera will autonomously follow your viewing attention. It frees the surgeon from laparoscope intervention so the surgeon can focus on instrument manipulation only."

To validate the effectiveness of this procedure, the team tested six participants on visualization tasks. Participants reported "they could naturally interact with the field of view without feeling the existence of the robotic laparoscope."

Zhang and Li anticipate that their technologies could have more than just healthcare applications, such as being used for the disabled and the elderly, who may have difficulty with upper-limb movements.

"Using this system, the surgeon can perform the operation solo, which has great practicability in situations like the battlefield and others with limited human resources," Li said.

Zhang and Li are working with clinical researchers and industry partners to commercialize their attention-aware robotic laparoscope.

FACULTY AWARDS

Toberer awarded Cottrell Scholar Award

Colorado School of Mines Assistant Professor of Physics Eric Toberer has received an award that will further his research into improving the conversion of heat into electricity, as well as support his pioneering techniques in teaching undergraduates higher-level physics.

The Cottrell Scholar Award is granted each year by the Research Corporation for Science Advancement (RCSA) to a dozen or so teacher-scholars who are just a few years into their first tenure-track position. The award provides $75,000 over three years.

"I'm excited about this award in particular as it embodies the Mines spirit — striving for excellence in teaching and research in equal parts," Toberer said.

Toberer's long-term research goal is to minimize the inefficiencies of thermoelectric generators, making them competitive with conventional engines.

While he and other researchers have been actively pursuing how a material's electronic band structure determines efficiency, Toberer's proposal to the RCSA also seeks to address what he calls "the missing link" in the computational prediction of thermoelectric performance: electron scattering.

Toberer said pursuing both these avenues will lead to the next generation of thermoelectric materials.

On the education front, Toberer will continue his active-learning approaches in upper-division solid-state physics. In the last two years, he has converted approximately half of his course content into YouTube videos, creating more time during class for activities and discussions with students. The videos have even been a hit beyond Mines, with about 41,000 views over the past year, 75 percent coming from outside the United States.

RCSA, founded in 1912, is the oldest foundation for science advancement in the United States.

RESEARCH

Professor unearths Moon's "Ocean of Storms" mystery

Colorado School of Mines Geophysics Associate Professor Jeff Andrews-Hanna is the lead author of a study documenting the discovery of a giant rectangular structure (roughly 1,600 miles across) on the nearside of the Moon. Using NASA's Gravity Recovery and Interior Laboratory (GRAIL) data, he is part of a team that examined the subsurface structure of the Procellarum region, also known as the Ocean of Storms.

GRAIL scientists believe the Ocean of Storm's rocky outline is the result of ancient rift valleys, and not an asteroid impact as some previous theories suggested. The lava-flooded rift valleys are unlike anything found anywhere else on the Moon, and may at one time have resembled the rift zones on the Earth, Mars and Venus.

GRAIL gravity data is now allowing scientists to look beneath the surface at structures that are hidden from view, using the subtle gravitational pulls on the orbiting spacecraft.

Using the gradients in the gravity data to reveal the rectangular pattern of anomalies, researchers can now clearly and completely see structures that were only hinted at by previous surface observations. This newly discovered rectangular pattern has an area of approximately 6.5 million square kilometers (or 2.5 million square miles) and covers 17 percent of the surface of the Moon.

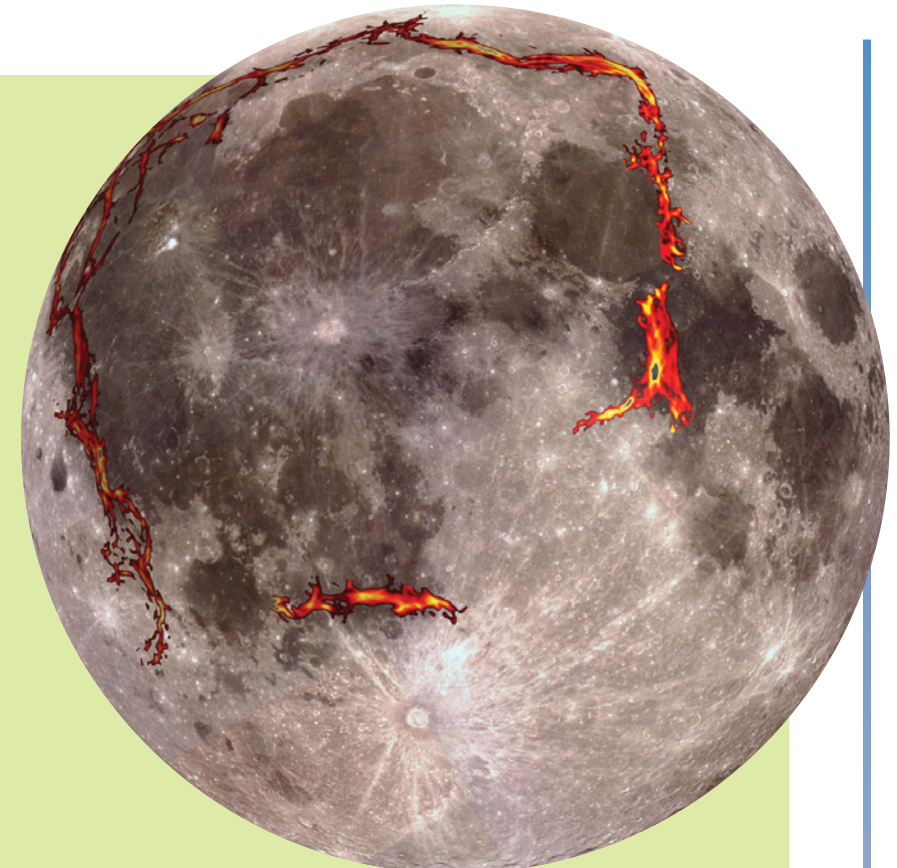
"This rectangular structure covers a larger fraction of the surface area of the Moon than do North America, Europe and Asia combined on the Earth," Andrews-Hanna said. "This goes to show that there are still big discoveries waiting for us on all of the planets."

The rectangular pattern with its angular corners and straight sides is at odds with the notion that Procellarum might be an ancient impact basin, as that hypothesis would predict a circular basin rim. Instead, the new work suggests that internally driven processes dominated the evolution of this region.

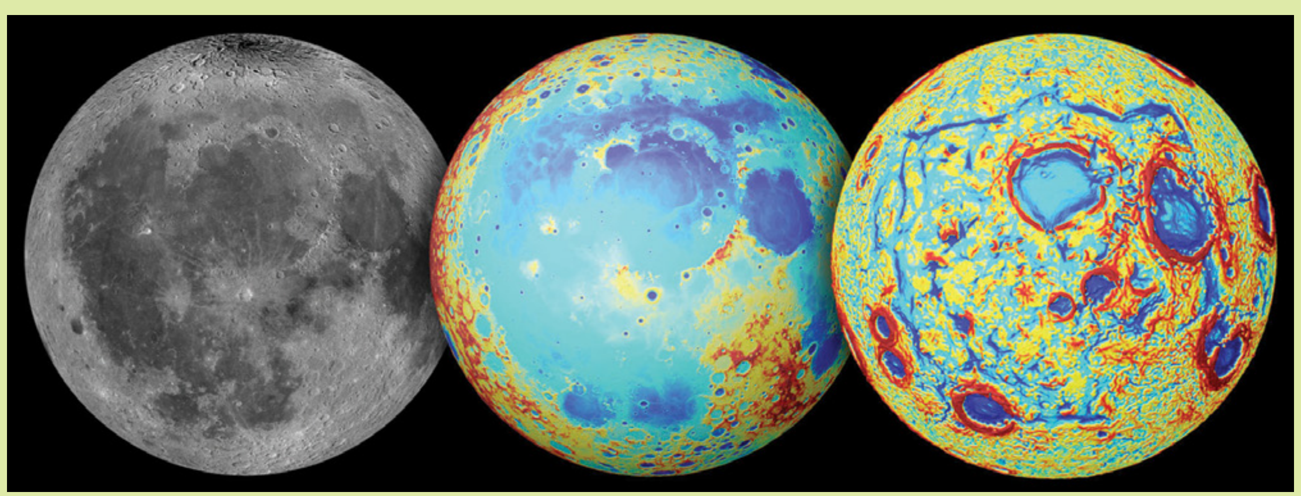
"Our gravity data is opening up a new chapter of lunar history, during which the Moon was a more dynamic place than suggested by the cratered landscape that is visible to the naked eye," said Andrews-Hanna.

The GRAIL mission was managed by JPL, a division of the California Institute of Technology in Pasadena, Calif., for NASA's Science Mission Directorate in Washington. The mission was part of the Discovery Program managed at NASA's Marshall Space Flight Center in Huntsville, Ala. GRAIL was built by Lockheed Martin Space Systems in Denver.

Andrews-Hanna's findings are published online in Nature. For more information about GRAIL, visit nasa.gov/grail and grail.nasa.gov.



The full Moon as seen from the Earth, with the Procellarum border structures superimposed in red.



The Moon as observed in visible light (left), topography (center, where red is high and blue is low), and the GRAIL gravity gradients (right). The Procellarum region is a broad region of low topography covered in dark mare basalt. The gravity gradients reveal a giant rectangular pattern of structures surrounding the region.

Kopernik Observatory/NASA/Colorado School of Mines/MIT/JPL/Goddard Space Flight Center

RESEARCH

Examining indoor air quality

According to the EPA, we spend 90 percent of our time indoors. Much of that time is spent without realizing that the air we breathe could be potentially dangerous to our long-term health. Department of Civil and Environmental Engineering Professor Tissa Illangasekare has spent the last five years researching how volatile organic compounds, which are commonly entrapped as non-aqueous phase liquids (NAPLs) or dissolved into groundwater to produce plumes, affect our indoor air concentration.

"We drink so many liters of water a day, but we inhale so many thousands of liters of air," Illangasekare said. (According to the EPA, the average American inhales close to 3,000 gallons a day.) "Sometimes we go to a contaminated site, test the water and we find it's clean but later we go inside the building and find the vapor is contaminated."

In 2009, Illangasekare and his research group, including a collaborator from the U.S. Air Force Academy, received funding from the Department of Defense Strategic Environmental Research and Development Program Office to improve their understanding of the processes and mechanisms controlling vapor generation from entrapped NAPL sources and groundwater plumes.

"We learned how contaminant vapors move preferentially through the ground and make their way into people's basements or crawl spaces," said Kate Smits, a professor in the Department of Civil and Environmental Engineering, who has worked with Illangasekare for the past five years. "We also discovered how this is influenced by changes in climate (e.g. temperature, wind conditions and precipitation)."

Illangasekare's research will impact closure decisions on waste sites based on vapor intrusion risks.

Tissa Illangasekare

News

FACULTY AWARD

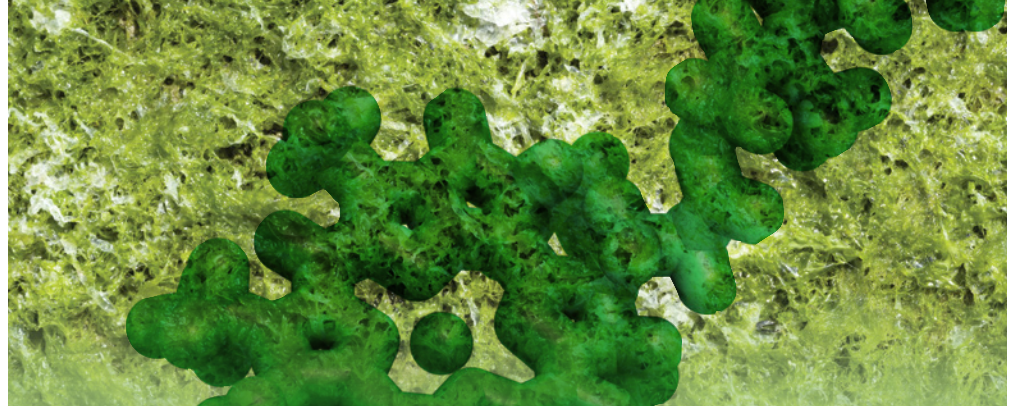
Speer receives Gibbs Award

John Speer, the John Henry Moore Distinguished Professor of Metallurgical and Materials Engineering, has been awarded the J. Willard Gibbs Phase Equilibria Award by ASM International.

The citation reads:

"For innovative applications of fundamental phase transformation principles in ferrous systems, development of quenching and partitioning process (Q&P) and contributions to phase equilibria education."

The Gibbs Award (that honors J. Willard Gibbs, one of America's greatest theoretical scientists) was established in 2007 to recognize outstanding contributions to the field of phase equilibria.



RESEARCH

Mines nets $10M in public and private funding for algal fuel research

The Energy Department recently announced funding for algae-based biofuels including up to $9 million for a research group involving Colorado School of Mines.

ExxonMobil has also committed up to $1 million during the span of two years to further research that will contribute to the long-term development of the next generation of sustainable algal biofuel technologies.

The Mines portion of the project funded by DOE, "Producing Algae and Co-Products for Energy," will build on research led by Matthew Posewitz, associate professor of chemistry and geochemistry, to enhance overall algal biofuels sustainability by maximizing carbon dioxide, nutrient, and water recovery and recycling, as well as bio-power co-generation. Collaborators include Los Alamos National Laboratory, Reliance Industries Ltd., and others.

The DOE aims to reduce the modeled price of algae-based biofuels to less than $5 per gasoline gallon equivalent by 2019. This funding supports the development of a bioeconomy that can help create green jobs, spur innovation, improve the environment, and achieve national energy security.

Posewitz's research partnership with ExxonMobil is focused on developing fundamental new insights into photosynthetic processes and carbon fixation in algae. These insights will provide better understandings of the scientific and technical challenges to developing biofuels from algae.

Posewitz, who has been studying algal biofuels for 13 years, said this funding allows his research team to expand their research focus.

"We think algal biofuels have a ton of potential. It is certainly a plausible, sustainable technology," he said. "This project will definitely open up some new doors for us." ExxonMobil researchers will work closely with Posewitz's team and will have a high level of involvement with the research.

"We expect the collaboration between ExxonMobil and Colorado School of Mines to shape the research and the interpretation of the results in a way that provides valuable new information toward solving tough technical challenges," said Mike Kerby, manager of Corporate Strategic Research at ExxonMobil. "That is why we partner with universities and leading researchers across the world in cutting edge scientific fields like next generation biofuels."

RESEARCH

Mines researcher part of $7 million award to study "rock-powered life"

The NASA Astrobiology Institute has awarded a team, including Colorado School of Mines Civil and Environmental Engineering Professor John Spear, more than $7 million to study "rock-powered life."

Spear is part of a team that is examining serpentinization reactions where an iron bearing rock reacts with water to make hydrogen, a primary fuel for microbial life.

"We hope to have a better understanding of what drives life in the subsurface," Spear said. "This team will allow geology to come together with geochemisty and microbiology to explain how the earth is more of an organism. For example, does that organism have a liver? Is our environmental liver the subsurface that processes everything and is keeping us all alive?"

Their "rock-powered life" data could potentially help inform researchers working with NASA's Curiosity Rover on Mars as well as future NASA missions.

"We're getting to where we're going to have 1,000 genomes from a single environment – we're looking at how those genomes fit together to explain their environment. Part of this project is looking at where science and the field of geobiology is going, and how what we learn applies to what's under our feet."

Spear is one of 13 co-investigators that includes scientists from CU-Boulder, Montana State University, Arizona State University, NASA Ames Research Center in Moffett Field, Calif., Michigan State University, the University of Rhode Island, the University of Utah and Massachusetts Institute of Technology.

RESEARCH

Redesigning robotic arms for stroke recovery

Mechanical Engineering professor Ozkan Celik and two Mines students have designed a robotic exoskeleton, named the Wrist Gimbal, which would assist stroke patients to complete repetitive movement therapy tasks. Based on a previous model Celik designed, this new robotic device focuses on two rotational degrees of freedom and would cost less than $5,000.

"The degree of freedom we eliminated was wrist abduction and adduction — which has the smallest range of motion among the three," Celik said. "Also, exercising wrist flexion and extension can be expected to benefit abduction and adduction as some muscles are involved in both movements."

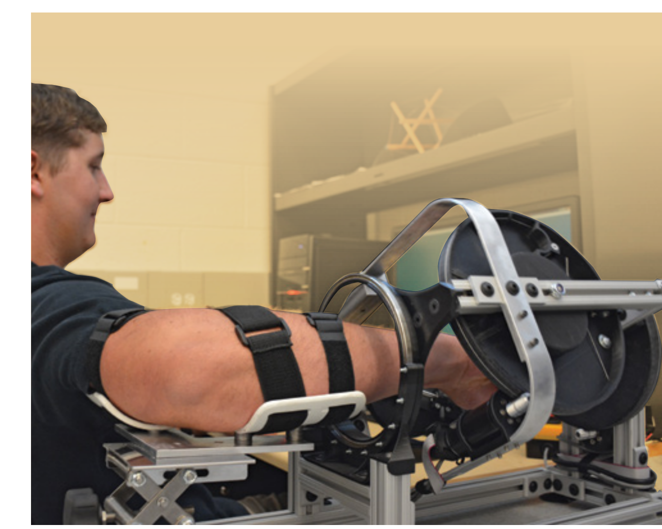
Since wheelchairs are not uncommon for stroke patients, the team developed a robotic exoskeleton that a stroke patient could be strapped into while seated. Patients would hold onto the device and use wrist movements to complete assessment exercises that would determine their maximum range of motion. The robot applies programmable force feedback to aid or deter movements, and records responses of the patients in particular tasks.

"The device provides motivation," Celik said. "Our game-like interface exerts assistive forces to stimulate patients and prompt them to complete exercises with assistance."

Student David Long worked on the mechanical design and 3D printed, machined and laser cut several of the parts of the device and specialized in the robot's control system.

Graduate student Hossein Saadatzi completed kinematic and dynamic modeling of the robot and developed an algorithm that allows real-time estimation of interaction torques between the patient and the robot. He presented this work at the 5th Annual Regional Meeting of the Rocky Mountain American Society of Biomechanics in April 2015.

Further development of the robot is currently underway, with funding provided by Mines Proof of Concept program through the Colorado Office of Economic Development and International Trade and the Mines Foundation.



Mechanical engineering student David Long demonstrates how to perform exercises using the Wrist Gimbal.

CAMPUS

Payne Institute for Earth Resources to inform policy domain

Colorado School of Mines' premier policy institute for earth resources has a new name: the Payne Institute for Earth Resources.

Thanks to a $5 million investment by Jim and Arlene Payne, the institute will move forward with plans to expand its leadership and reach. The Payne Institute will educate and inform policymakers and other stakeholders about pressing issues in the areas of earth, energy and the environment. Through research and policy analysis, the Payne Institute will foster collaborative partnerships with established research institutions, universities and government agencies around the world.

Originally established as the Earth Resources Institute in 2014, this new investment not only renames the organization, but enables the Payne Institute to propel its growth and enhance Mines' role as a global public policy leader in these focus areas.

"My vision is to leverage the Institute's first-class academic research and have it serve as the go-to resource for those engaged in public policy discourse on some of the challenges shaping our future," said Jim Payne, who earned his professional engineering degree in geophysics from Mines in 1959.

The Payne Institute is a campus-wide initiative, led by Mines' Division of Economics and Business and the Office of the Provost. "The Payne Institute provides Mines an institutional base from which to leverage a rich set of faculty resources across campus," said Division Director Michael R. Walls, who is spearheading the effort. "Mines is already known as one of the nation's top engineering and applied science universities, and the Payne Institute will open a wealth of opportunities to expand our innovative and influential quantitative analysis in the policy arena."

COLORADO SCHOOL OF MINES
PAYNE INSTITUTE
for EARTH RESOURCES

Research at the Payne Institute will promote analysis based on sound economic and scientific principles. Areas of research will include rare earths and critical materials, climate and carbon policy, pollution regulation, global trade and the environment, minerals policy, energy security and more.

Jim Payne retired as the CEO and Chairman of Shona Energy Company in 2013, and was previously the chief executive of several companies including Nuevo Energy Company, Santa Fe Snyder Corporation and Santa Fe Energy after a career with Chevron Oil. He has served as chairman of the Domestic Petroleum Council and the Offshore Energy Center as well as a board member of the American Geological Institute Foundation. In addition, Payne has served as an outside director on several service industry boards. He and his wife, Arlene, split their time between Pagosa Springs, Colo., and Fredericksburg, Texas.

CAMPUS

Educating engineers to meet the Grand Challenges

Colorado School of Mines has joined with more than 120 U.S. engineering universities in committing to an initiative dedicated to educating a new generation of engineers equipped to meet the grand challenges society faces today and in the future. The commitment was unveiled at the 2015 White House Science Fair.

Mines College of Engineering and Computational Sciences Dean Kevin Moore joined other U.S. engineering deans in meetings at the White House with the President's Science Advisor and at the National Academy of Engineering.

According to an MOU signed by the engineering deans, the contingent will work together to plan ways to achieve the goal of educating engineers and scientists who have "... the broader understanding of behavior, policy, entrepreneurship, and global perspective; one that kindles the passion necessary to take on challenges at humanity's grandest scale."

In a letter to President Barack Obama, Moore detailed efforts underway at Mines integrating five key elements outlined in the U.S. Engineering Dean's response to the National Academy of Engineering's Grand Challenges program. Efforts at Mines include enhancement of the university's Humanitarian Engineering minor with the addition of social entrepreneurship and innovation opportunities and revision of the accredited Bachelor of Science in Engineering degree to include a Grand Challenges track.

"It is becoming more and more widely understood that to continue to improve the human condition for all people on the planet it will take more than engineering prowess — engineering students must learn to be problem definers as well as problem solvers."

"To make a difference they must understand the complexities of the techno-socio-natural contexts that constrain solutions; they must be part of deciding what to solve as well as how to solve it," Moore said.

RESEARCH

Funding fuels nuclear energy research

The Department of Energy has announced millions in research awards for U.S. universities, national laboratories, and industry, for nuclear energy research and infrastructure enhancement with the potential to create scientific breakthroughs that will help strengthen the nation's energy security and reduce harmful greenhouse gas emissions.

Mines projects include:

Infrastructure award, $215,372: Led by Jeff King, associate professor, Mines Metallurgical and Materials Engineering Department and interim program director of the Mines Nuclear Science and Engineering Program

The project will provide the Mines Nuclear Science Laboratory with a pneumatic sample transfer system to transfer irradiated samples from the U.S. Geologic Survey TRIGA Reactor to the Mines laboratories at the Denver Federal Center. The project will also provide remotely accessible experimental stations for work with radioactive materials.

R&D award, $800,000: Led by Jenifer Braley, assistant professor, Mines Chemistry and Geochemistry Department

The significant storage timelines associated with managing used nuclear fuel (>100,000 years) limits its attractiveness as a largely carbon-neutral source of energy. Researchers will develop and exploit the fundamental chemistry of Americium to enable an industrially viable means to co-recover the U-Am actinide elements from used nuclear fuel. The results would be a significant step forward in the development of aqueous separations approaches designed to recover the U-Am actinides based on the availability of the hexavalent oxidation state.

R&D Award, $375,000: Led by Moises Carreon, associate professor, Mines Chemical and Biological Engineering Department

The project will explore developing novel types of porous crystalline membranes, capable of effectively separating Kripton from Xenon with high flux and selectivity. These membranes have the potential to advance the conventional high-energy intensive process (fractional distillation at cryogenic temperatures), commonly used to separate radioactive Kripton from gas mixtures.

Mines is collaborating with materials sciences scientist Praveen Thallapally at Pacific Northwest National Laboratory for expertise on adsorption studies that will help to potentially elucidate separation mechanisms through these membranes.

R&D Award, $746,076: Led by principal investigator Kip Findley, associate professor, Mines Metallurgical and Materials Engineering Department, along with Michael Kaufman, professor and dean of the College of Applied Science and Engineering, and Richard Wright of the Idaho National Laboratory

The project is focused on how Alloy 709, a high-Ni stainless steel, behaves under accelerated testing conditions.

A primary goal of the project is to provide a better understanding of the potential use of this alloy in structural applications for advanced nuclear reactors. This alloy will be subjected to conditions that simulate long-term exposures at service temperatures and will include conducting both creep and creep-fatigue tests. After testing, the materials will be characterized using the various advanced analytical characterization techniques available at Mines.

Integrated Research Project Award, $3 million: Led by Zeev Shayer, research professor, Mines Department of Physics, with Metallurgical and Materials Engineering Department Professors David Olson and Stephen Liu, and Assistant Professor Zhenzhen Yu

The team will study the deterioration of canisters used for storing spent nuclear fuel. Stress corrosion cracking of spent fuel canisters, initiated by the presence of chlorides, could lead to the release of helium and radioactive gases. It can also let in air, which poses a threat to the integrity of the fuel rod. The study will improve understanding of the conditions that encourage stress corrosion cracking — temperature, salt concentrations, humidity, and other factors, determine which parts of the canister are most susceptible, and develop methods for identifying it in its early stages.

Researchers will use what they learn to determine the best means of evaluating canister surfaces on-site without damaging them.

New Faculty

Making an impact on students and the world through innovative classroom experiences and critical research, the award-winning faculty at Mines are advancing scientific and technological discoveries.

2015 NEW TENURE/TENURE TRACK FACULTY

Hazim Abass Professor
Department of Petroleum Engineering

Jared Carbone Associate Professor
Division of Economics and Business

Kevin Cash Assistant Professor
Department of Chemical and Biological Engineering

Emmanuel De Moor Assistant Professor
Department of Metallurgical and Materials Engineering

Alexander Gysi Assistant Professor
Department of Geology and Geological Engineering

Ian Lange Assistant Professor
Division of Economics and Business

Aaron Porter Assistant Professor
Department of Applied Mathematics and Statistics

Svitlana Pylypenko Assistant Professor
Department of Chemistry and Geochemistry

Susanta Sarkar Assistant Professor
Department of Physics

Timothy Strathmann Professor
Department of Civil and Environmental Engineering

Gongguo Tang Assistant Professor
Department of Electrical Engineering and Computer Science

Nils Tilton Assistant Professor
Department of Mechanical Engineering

Shubham Vyas Assistant Professor
Department of Chemistry and Geochemistry

Bo Wu Assistant Professor
Department of Electrical Engineering and Computer Science

Zhenzhen Yu Assistant Professor
Department of Metallurgical and Materials Engineering

Jeramy Zimmerman Assistant Professor
Department of Physics

Hao Zhang Assistant Professor
Department of Electrical Engineering and Computer Science

"My favorite subject for classroom lectures is the natural nuclear reactors that existed at Oklo in West Africa. They bring together actinide chemistry, nuclear physics, geology and hydrology into an amazing story. Very few people have ever heard that nature created the first nuclear reactors on Earth many eons ago, and still fewer understand the implications for radioactive waste disposal today."

MARK JENSEN

Jerry and Tina Grandey University Chair in Nuclear Science and Engineering and Professor
Department of Chemistry and Geochemistry

Jensen's research focuses on the chemistry of the actinide elements — the radioactive elements at the very bottom of the periodic table. His research group is working to understand how the unique chemistries of these elements influence their behaviors in separations, the environment, and even in the human body.

From a fundamental perspective, the actinide elements are a sort of "missing link" between other, more mundane, parts of the periodic table, he said. Understanding the chemistry of these mainly artificial elements helps researchers to understand how different parts of the periodic table fit together. And from an applied perspective, Jensen said the actinide elements are important components of nuclear energy production.

"Most actinides are highly toxic and actinides are the largest contributors to the long-term toxicity of used nuclear fuel. If we understand more about their chemistries, we could greatly reduce the amounts of the actinides that become radioactive waste."

New Faculty

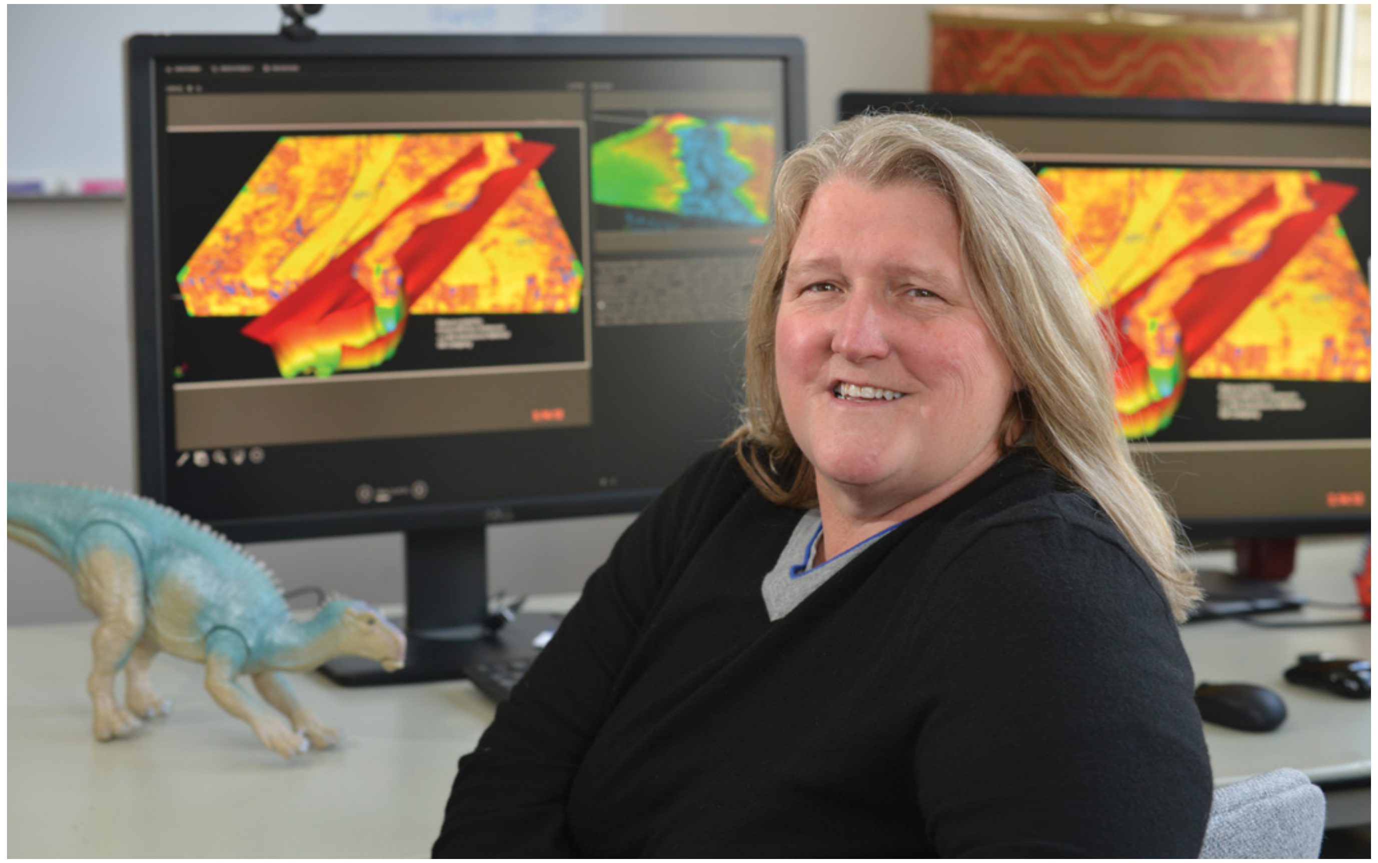
"From new high-strength steels and aluminum alloys enabling safer and higher efficiency vehicles, to the microelectronics systems that allow us to carry around the entire Internet in our pockets, materials are very often the unsung heroes of technological advancement. By developing new materials with unprecedented properties or methods for integrating known materials into new systems, we help provide electrical, mechanical, civil and other engineers with more capable tools to create the marvels of the modern world."

GEOFF BRENNECKA

Assistant Professor
Department of Metallurgical and Materials Engineering

Brennecka works on ceramics — primarily high performance dielectrics, ferroelectrics, and piezoelectrics — that respond in useful and often nonlinear ways to electric fields. Much of his work deals with understanding and controlling the dynamic responses of these materials, from ferroelectric domains that switch in nanoseconds, to defect-induced degradation over decades of operation.

"My research group is developing cheaper and more reliable capacitors needed for next-generation power electronics systems to allow greater use of renewable energy sources on the grid; improving the materials used in the micro-electro-mechanical resonators that enable our cell phones to wirelessly communicate; and understanding the fundamental physics underlying dynamic ferroelectric behavior to continue to solve future problems."



LESLI J. WOOD

Weimer Distinguished Chair and Professor in Sedimentology and Petroleum Geology
Department of Geology and Geological Engineering

Wood studies landscapes, also known as geomorphology, or the study of landforms. But she doesn't limit herself to the modern landscape — Wood also studies the landscapes of other worlds, such as Mars and other planets, as well as in Earth terranes dating back 600 million years.

Understanding where and what types of rivers flowed, marine and terrestrial landslides occurred, submarine fans built, and shorelines evolved, helps predict phenomena such as when and how rivers will flood and help inform how we can respond to geomorphic evolution. The data is used to help search for mineral wealth, understand ancient climates and plan for catastrophes.

"Our 'education through research' program is very student-focused. It is important that scientific research be used to educate a new generation of scientists and leaders of tomorrow's companies and governments. Society needs more and more earth scientists who know how to communicate their ideas to the public."

"The Earth is increasingly asked to give more and more to a growing society. It is important that we explore for resources with as minimal a 'footprint' as possible and such endeavors will require collaboration among lots of disciplines and integration of new technologies into our tried and true approaches. To understand and predict the Earth's response to future changes, we must understand how the landscapes have evolved and changed over time."

New Faculty

“As the global population increases, the demand for mineral resources is rising. My research will help provide methods and tools to enhance extraction practices in a sustainable, economically viable and environmentally responsible fashion.”

RENNIE KAUNDA

Assistant Professor
Department of Mining Engineering

Kaunda looks at innovative and sustainable solutions to tackle challenging problems in mining operations, excavation engineering and earth material processes. He uses intelligent rock mechanics, geotechnical engineering principles and other interdisciplinary fields to address characterization, stability, ground control and fragmentation optimization challenges in mining.

One of his favorite classroom activities is assigning creative group projects to students that challenge their thinking and problem solving skills.

“Studies have shown that such student-centered learning activities enhance student learning and retention of material, logical thinking skills and deeper understanding. I attempt to make these classroom exercises fun, relevant and contemporary where applicable.”

PAULO TABARES-VELASCO

Assistant Professor
Department of Mechanical Engineering

Tabares-Velasco focuses on multi-scale building energy analysis, and thermal storage.

“I am very interested in looking at buildings, not from their classical and individual passive role of energy users, but from a more active role that combined with thermal storage can increase flexibility to the electric grid.”

He is looking beyond how building precooling or other building thermal storage technologies address important utility challenges associated with high penetration of renewable electricity generation due to intermittency and forecasting uncertainty; electric peak demand associated with air conditioning; and contingency and regulation without impacting occupants’ comfort. Tabares-Velasco is working on a project that will simulate all buildings on the Mines campus to analyze their mutual thermal interactions, campus energy performance and impact on the electric grid.

“Buildings use about three-quarters of the total electricity generated in the United States. What is more, during summer months, buildings account for approximately 56 percent of electricity demand. Thus, buildings combined with thermal storage can be one of the solutions for the grid of the future.”

My Dark Path to the Bio Side

A PROFESSOR'S TRANSITION FROM CHEMICAL TO BIOLOGICAL ENGINEERING

By David Marr

Marr is professor and head of the Mines Department of Chemical and Biological Engineering.

(Excerpted from the 2014 Mines Faculty Senate Distinguished Lecture.)

I began my Mines career in 1995 studying thermodynamics — in many ways a traditional chemical engineer. However, when I was in graduate school, I saw a talk by Stephen Chu, physics professor and (more recently) former U.S. Secretary of Energy, who discussed "optical trapping," basically the ability to use focused laser beams to control and manipulate small colloidal particles.

For those of my generation, this is the tractor beam.

Because I loved Star Trek growing up, I started my own experimental program at Mines in this area. The approach is based on using momentum pressure from individual photons — clearly very fundamental physics — but I applied them in a very engineering way using these small particles (typically 1-10 microns in size) as the building blocks of devices for nanotechnology. With this, my research group was using lasers to do true engineering as we were fabricating microscopic valves, mixers, and even the world's smallest pump.

What began my interest in biomedical engineering was application. You may have heard of "lab-on-a-chip," the idea of a single hand-held device that can diagnose disease. With the goal of using a single drop of blood or saliva, this device would allow determination of illness at the point of need or care, avoiding a trip to the doctor's office and greatly lowering costs.

Since 1960, health care costs have exponentially risen in the U.S. while the population has not even doubled. As Baby Boomers currently make up a quarter of the U.S. population, health care costs are projected to nearly double in the next decade. With the elderly requiring significantly more health care, the need to improve diagnosis and treatment methods may be critical for the U.S. to avoid spending huge amounts of our national budget on health care.

The question, however, is how can Mines, with its historical focus on resource engineering, contribute to this vital national need?

Mines has had relatively little funding by the National Institutes of Health over the years; but with the establishment of the National Institute of Biomedical Imaging and Bioengineering in 2001, there was clear recognition of the need for engineers to develop new methods for the treatment of disease.

With Mines' focus on technology, we clearly have a role to play. Here we have employed microfluidics, the science and engineering of flow at small length scales, as an enabling technology for device development. Without formal training in the biosciences and bioengineering, I have applied core skills learned in chemical engineering and physics to create devices of interest to the biomedical community that sort and measure blood cells and have been funded on numerous NIH grants.

> "My research group was using lasers to do true engineering as we were fabricating microscopic valves, mixers, and even the world's smallest pump."

Bio has also seen growing importance in the Mines curriculum as well as in our research programs. This link between biology and engineering has been clear to our students for many years and was initially supported with the formation of the Bioengineering and Life Sciences program in 2001. This continued with the initiation of the Chemical and Biochemical Engineering degree in 2008.

This degree program is comprised of about 50 percent women at an institution where the total population of women is around 27 percent. The figure is not atypical as the disciplines of environmental engineering, chemical engineering and biomedical engineering all have traditionally been sought after at higher rates by women than other engineering disciplines. As a result, I believe expansion in these areas will better support and encourage the growing population of women coming to Mines.

Mines is the eighth largest graduator of undergraduate female engineers in the U.S. and we continue down the right track with efforts in many departments and more opportunities available every semester. There are now formal programs in biomedical engineering, biophysics, biochemistry, and biomechanics available to students to supplement their degrees. As these programs grow, additional opportunities will appear at the graduate level as well, as we continue to hire faculty whose interests integrate these programs with their traditional engineering disciplines.

Modern METAL

Mines' Advanced Steel Processing and Products Research Center transitions alongside industry during 30 years of collaborative work

The 1959 Chevrolet Bel Air looks prepped for a vintage auto show, but a different fate awaits. All fins and sharp edges, it takes off straight at a silver teardrop of a Chevy Malibu a half-century younger.

The closing speed is 80 mph, notes University Emeritus Professor David Matlock, a member of the National Academy of Engineering, whose computer monitor presents this generational clash.

The crash-test dummy is crunched in the collapsed cabin of the '59. The one in the '09 sits as it had before, spared by advances in automotive engineering and high-strength steel. There are many kinds of steel in a modern vehicle frame, Matlock explains, each designed with an exact set of properties which, in combination, has helped make cars much safer.

Matlock co-founded Mines' Advanced Steel Processing and Products Research Center (ASPPRC) in 1984 with University Professor Emeritus George Krauss. By the early 1980s, American steel-industry research labs had begun to shrink and university funding for ferrous metallurgy had all but disappeared. Krauss and Matlock approached steel companies with the idea of partnering on a university-industry steel research center, in which a consortium of industry competitors, suppliers and customers would discuss the industry's unmet research needs, set the science agenda and share results. Mines strengths in ferrous metallurgy research and teaching made it a logical hub.

Six companies signed on, and the National Science Foundation provided seed funding. The center survived a variety of changes in the landscape, including significant industry consolidation in the early 2000s, with member companies merging (for example, five of the current members now represent what was at one time 18 discrete ASPPRC members) as well as globalization of the steel and manufacturing industries.

Constant throughout, though, has been a focus on the research needs of industrial-partner member companies that include many of the world's biggest names in steel, automotive, heavy industry and oil and gas. In addition to annual dues to the center, they commit to sending one or more staff to biannual meetings in Golden where students present, and companies and researchers map the road ahead.

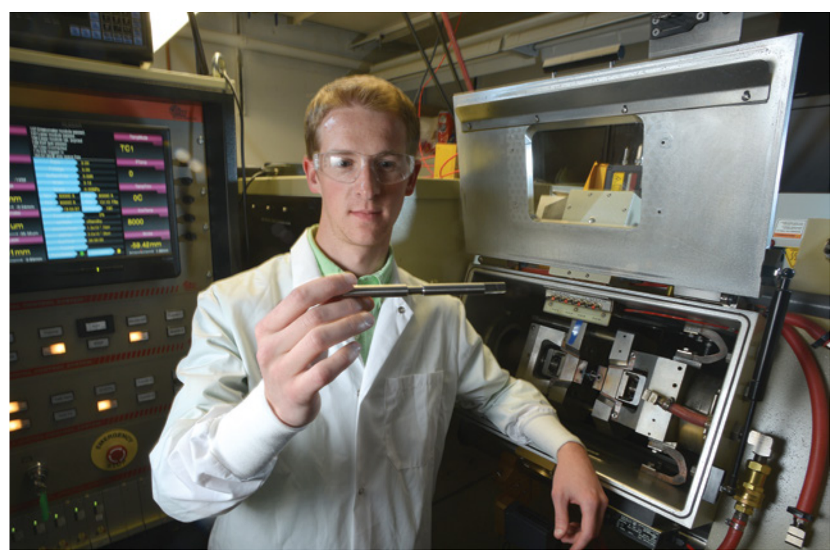
Graduate student Zahra Ghanbari, Professor John Speer, graduate student Oscar Terrazas and Professor Emeritus David Matlock hold sheet steel formability specimens.

Thirty-one years since its founding, the ASPPRC's focus on collaboration continues, with 31 companies from 13 countries now jointly setting the course and sharing the fruits of advances in testing methodologies and alloying strategies, and production processes. Eight full or part time Mines faculty lead a team of five research assistants, four postdoctoral researchers and 31 graduate students on a wide array of projects.

Member companies have hired many of these ASPPRC students, including Grant Thomas, a research engineer at AK Steel in Middletown, Ohio, who earned his Mines master's and doctorate degrees for his ASPPRC work. The center, he said, is "industrially driven, so they're relevant, and they have the time, the resources, and the equipment that really lets them get to the core of the problem — or opportunity, which are one in the same."

Wang Li, a senior engineer and member of the board of directors at China's Baosteel, the world's fourth-largest steel producer, cited four major benefits in its ASPPRC membership: sponsors share in the center's research achievements; it's a good platform for interaction with other sponsors, including steel producers and users; it's an opportunity for Baosteel staff to get involved in automotive steel research (Baosteel has a researcher doing a fellowship at the ASPPRC); and in helping set the research agenda, Baosteel gains early insights into trends in automotive steel.

All members receive royalty-free licenses for technologies that emerge from the center's work. Despite many members being competitors, the nature of the business helps this sharing model work, said AK Steel's Thomas. Fundamental insights into the behavior of a certain type of steel processed in a certain way — the ASPPRC's calling card — can be taken different directions by different firms, all



Graduate student Blake Whitley at the Gleeble thermomechanical simulator, inspects a test specimen used for multipass torsion simulation.

who have proprietary production techniques and established lines that can cost hundreds of millions of dollars.

"That's where the competitive part comes in: putting it to use in a specific mill," Thomas said.

Mines Professor John Speer, who has been ASPPRC director since 2013, spent 14 years at Bethlehem Steel before coming to Mines in 1997, said "we work hard to be relevant because many of the sponsor companies have outstanding corporate research facilities of their own. If the companies become interested in working on an idea we are pursuing, they can put a lot of people on it very quickly. Some of these companies have a thousand researchers."

"Mines' advantage," he said, "is time."

"If you're fighting the daily fires of industry, it can be more difficult to sit back and think about the fundamentals," Speer said, "or on potential processing routes that do not match existing facility investments."

The ASPPRC's research focuses on simulating solid state processing done on steel (after it has solidified), explained Assistant Professor Emmanuel De Moor. Important considerations can include combinations of alloying, heating, cooling, or changing its shape at different temperatures.

The center is focused on three major categories of steel: sheet, bar and plate. Sheet steel research is mainly driven by automotive needs; while bar steel research includes cables, gears, crankshafts, axles and wire; and plate steel activities are related to oil and gas pipelines, earth moving equipment, wind-turbine towers, ships, etc.

If the center's research has a common focus, it's on microstructure and properties. De Moor, an alloying and thermochemical processing expert, is interested in microstructure along with Associate Professor Kip Findley, a mechanical-properties specialist whose students spend their days analyzing steel properties and performance. Microstructure, they explain, dictates the steel's ultimate strength, ductility, formability and hardness.

Caryn Ritosa, a PhD student, is doing her work on the Gleeble 3500, a thermomechanical processing simulator — in this case mimicking an industrial process called multi-pass plate rolling. She's testing six different steels, each about as thick as a pencil representing the thick plate steel used in pipelines. They're low-carbon, with microalloying additions such as niobium, vanadium and titanium. Ritosa heats each to an orange-red 1,250 degrees Celsius, then commands the Gleeble to twist them 180 degrees, 360 degrees and beyond. Her goal, she said, is to understand how the steel's recrystallization behavior at high temperature affects its microstructure, with the ultimate goal being to produce higher-strength steels at lower cost.

In another lab around the corner, PhD student Lee Rothleutner is fatigue-testing thumb-thick bars, each hourglassed along the length, of induction-hardened steel. Automakers are interested in improving this steel for drivetrains, he said. Automotive lightweighting is a hot topic in steel, informing many ASPPRC experiments: average light-duty fuel economy standards are poised to leap from today's 32.5 mpg to 54.5 mpg in 2025. The less a car weighs, the less fuel it takes to move it.

"The drivetrain is really one area of the automobile that hasn't been intensely lightweighted," he said. He mounts an article specimen in a fatigue tester that rumbles at a motion-blurring 30 hertz. As Rothleutner works the machine, Findley explains, "Over time, he'll look at alloying effects, processing effects and some in combination. Which has a better fatigue life? Where are the cracks initiating? How?"

Back in Matlock's office, shelves of engineering books share space with scores of snapped bits of steel whose failures helped keep so many drivers alive.

STEEL INDUSTRY MINDS MINES' Q&P

An important innovation that has emerged more recently in the Advanced Steel Processing & Products Research Center's three-decade history is poised to change the sheet-steel business. The advance — a process called quenching and partitioning (Q&P), promises to strengthen sheet steel of the sort used for auto bodies by a factor of two. That, in turn, could contribute to a reduction in vehicle weight by perhaps 20 percent. That's more than the roughly 15 percent Ford was able to shave by going with aluminum body panels on its latest F-150 truck.

"Q&P is one of the approaches being actively pursued to provide the next generation of steel for auto bodies," said Professor John Speer, who directs ASPPRC. "In comparison with other materials, steels can be very strong, with attractive characteristics such as weldability, formability, low cost and recyclability."

It was Speer's insight that led to Q&P. Data that appeared on the fringes of a student project sparked his curiosity, and Speer had other students work to test the theories that were developed and better explain and characterize the concept and, ultimately, show how Q&P can create a particularly strong, ductile third-generation advanced high-strength steel.

Understanding what Q&P actually entails takes serious metallurgical chops. It involves carbon partitioning between ferritic and austenitic phases of iron to stabilize the austenite and contribute to properties via transformation-induced plasticity.

China's Baosteel, the major sheet-steel supplier to the world's largest automotive market, was the first to bring Q&P to full-scale production in 2009. Wang Li, a Baosteel senior engineer and member of the board of directors, said the process will be launched on a second line in late 2015 and a third in 2017. It's a major investment, he said, in a business where a new commercial production line can cost $1.6 – $2 billion. But, he added, as Baosteel expands to accommodate demand for high-strength, lightweight steel for China's rapidly growing auto industry, "we have many chances to build new lines, and the Q&P process is easy to design or consider in new commercial lines."

There is strong interest in third generation advanced high strength steel development at AK Steel, which supplies to every major auto manufacturer in the U.S., said Grant Thomas, an AK Steel research engineer who earned his Mines PhD in 2012 for advancing the fundamental understanding of Q&P.

"We're in the lab trying to validate and justify it," he said. "I have a hunch there are other companies doing the same thing around the country and the world."

For now, Thomas and Speer are both unaware of any domestic facilities that are in full-scale production.

"I think that's about to change," Thomas said.

Gaining Steam

Using conventional hydrocarbon extraction expertise to tap renewable geothermal energy sources

A steady, reliable, enormous, practically inexhaustible, carbon-free source of electric power, one capable of producing three times the wattage the United States generates each year, is right under our feet. Or more accurately, way under our feet, where it has long tantalized geothermal energy experts.

Now the very technologies that ushered in America's oil and gas boom may be putting this resource within reach. A collaboration between Mines and the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) is working across several fronts to use the tools of modern hydrocarbon extraction to exploit a potentially game-changing clean energy resource.

The concept behind enhanced geothermal systems (EGS) is simple: inject water into hot, dry rock; let the hot rock heat the water; extract the hot water as a steam; drive a turbine with the steam; produce electricity; re-inject the cooled-off water and repeat. Appropriately enough for an infernal, netherworldly resource, the devil is in the details.

The Mines-NREL "Colorado Collaboration for Subsurface Research in Geothermal Energy" (Colorado SURGE) is getting into those details on projects spanning geothermal reservoir characterization, drilling approaches and water treatment. The effort, launched in 2014, is being paid for by funding from DOE starting with $800,000 in 2014 and $1.2 million in 2015. Future years funding will depend on the progress and independent review of proposals, but the Colorado SURGE team is planning for growth.

"The idea of adapting advanced oil and gas technologies for geothermal was a very high priority for the DOE," said Dag Nummedal, who directs Mines' Colorado Energy Research Institute and worked with NREL to launch SURGE. In early 2015, Mines Professor Wendy Harrison, just back from an 18-month appointment leading the National Science Foundation's Earth Sciences Division, took over SURGE leadership at the school.

A 2008 U.S. Geological Survey estimate considering the heat below 13 western states suggested a potential geothermal resource of 345 gigawatts to 727 gigawatts.

The entire U.S. electrical generation capacity amounted to 1,051 gigawatts in 2011.

Graduate student Robert Duran and Associate Professor Wendy Zhou conduct a scanline survey on discontinuities in rock mass in Colorado School of Mines' Edgar Mine in Idaho Springs.

Tom Williams, who directs NREL's Geothermal Technologies Program and federal lab's side of SURGE, said NREL had recognized that the lab lacked capabilities in geology, oil and gas technology, water treatment and other areas critical to EGS — not to mention access to students. Mines, right up the road, was the obvious choice, he said.

The conclusion so far, said those involved, is that while the technology piece is tough, the real hurdles are economic. The key, they said, will be to improve an array of technologies and techniques, particularly on the drilling side, to bring the costs down.

First, a bit about the potential prize. A 2008 U.S. Geological Survey estimate considering the heat below 13 western states suggested a potential geothermal resource of 345 gigawatts to 727 gigawatts. In 2011, Google.org and Southern Methodist University's Geothermal Laboratory estimated the "technical potential" of enhanced geothermal (that is, accessible at depths of 3.5 to 6.5 km and excluding places like national parks and other protected lands), to be 2,980 gigawatts. To put that in perspective, the entire U.S. electrical generation capacity amounted to 1,051 gigawatts in 2011. What's more, geothermal energy produces baseload power, a steady source that doesn't care if the sun is shining or the wind is blowing.

But you've got to get down there, and the shallow side of EGS is the deep end of oil and gas drilling. To tap into temperatures above 150 degrees Celsius (302 degrees Fahrenheit, the minimum for geothermal power production) in places like Michigan and Florida, you'd need to drill down about 10 kilometers — deeper than Mount Everest is tall. And that's just the beginning.

The most favorable EGS targets in the West are in granitic rock, as opposed to the sedimentary formations where tight oil and gas are harvested, "So drilling's a lot slower," said Professor William Fleckenstein. How hydraulic fracturing might work in such rock at high temperatures and pressures isn't well-understood, either. EGS wells will need larger diameters, adding to costs that an MIT team estimates will be twice to five times more costly than an oil and gas well. Factor in that the oil and gas drilling costs skyrocket with depth, with an average of $600,000 at a depth of two kilometers leaping to $10 million or more at six kilometers, the MIT team found.

Covering costs like that will take a lot of hot water, said Associate Professor Bill Eustes, one of the principal investigators for Mines' SURGE research. NREL estimates a barrel of EGS brine to be worth maybe 50 cents, or about 100 times less than a barrel of oil. So the Mines/NREL team has made 100,000 barrels of water a day its baseline flow — 10 times that of a big-producing oil and gas well, said Assistant Professor Luis Zerpa.

Zerpa's team is adapting oil and gas reservoir models for EGS in sedimentary basins. Traditional geothermal involves crystallized rock, Zerpa said, but sedimentary rock is much more common under the continental U.S. They're considering vertical drilling for now, but will soon be modeling horizontal wells. So far, EGS looks like "a technical challenge that can be overcome," he said.

Associate Professors Wendy Zhou and Masami Nakagawa are leading work on an EGS test at the university's Edgar Mine in Idaho Springs, Colo., which will be used to understand rock-water heat transfer and how fluid flows through fractures in igneous rocks. Zhou's expertise in 3D subsurface modeling is coming into play, as the positioning and angling of boreholes will depend on the orientation of joints, fractures, faults, bends and other rock discontinuities, among other factors.

Eustes and Fleckenstein have two undergraduates and a graduate student looking at the feasibility of horizontal geothermal completions. Other graduate students are doing EGS fracture stimulations and studying thermal cycling on casing strings and other drilling hardware. Nine Mines undergraduates are looking at drilling performance of oil and gas versus traditional wet-rock geothermal, trying to tease out the limitations and gain insight into what might be done to improve drilling operations, Eustes said.

Water quality will be an important part of EGS operations. "If you recirculate it again and again through a porous medium, you pick up particles and sand grains," said Associate Professor Tzahi Cath, who directs Mines' Advanced Water Technology Center (AQWATEC) and leads two EGS-related projects. "If you don't take the impurities out, you can plug the injection well."

One of Cath's EGS projects, part of SURGE, involves enhancing a water modeling system his team developed for the oil and gas industry. It takes into account factors including how dirty the input water is, the required level of purification, treatment approaches (chemical, distillation, nanofiltration, reverse osmosis), electricity or heat constraints, and an economic module that costs out infrastructure. About 30 undergraduate chemical engineering students are working on different EGS "water treatment trains" developed from the model's predictions as part of their capstone work, Cath said.

Cath's other EGS work is on a three-year, $2.6 million DOE-funded project with Yale University. Started in 2013, it involves using the heat from water at temperatures expected at the tail end of an EGS power plant to drive two membrane processes (membrane distillation and pressure-retarded osmosis), harnessing chemical energy to create mechanical energy to drive a turbine. A bench-scale machine is up and running and a pilot-scale system is nearing completion.

Mines and other EGS researchers around the world have a long way to go. Globally, EGS is in the demonstration stage, with commercial deployments yet to come. But Williams said DOE is playing the long game, and he sees EGS as a "very early-stage technology," akin to photovoltaics in the early 1960s, when solar panels cost thousands of dollars per watt (today, rooftop panels can be had for less than $1 a watt).

EGS, at the nexus of energy and the environment, "fits beautifully into the long term mission and vision of Mines," Nummedal said. "Students keep coming here because this is a vision they're increasingly aligned with. It's not one or the other anymore – it's both."

Graduate student Skylar Zilliox, Assistant Professor Jessica Smith and undergraduate Austin Shaffer stand near an Encana drill site located near Firestone, Colorado.

The IMPACT of agreement

Researching memorandums of understanding between communities and the oil and gas industry to ensure protection as well as progress

The stage was set for showdown. In one corner were Encana Oil & Gas Inc. and Anadarko Petroleum Corporation, both seeking to further tap into the Wattenberg Gas Field in northeastern Colorado. In the other was the town of Erie, where residents of the community straddling Boulder and Weld Counties were pushing for a drilling moratorium.

Erie wasn't alone: Longmont, Lafayette, Broomfield and Boulder County considered, and ultimately instituted, moratoriums, which in turn triggered lawsuits. But then something interesting happened in Erie.

The town's Board of Trustees approved an emergency six-month drilling ban. But rather than duke it out in court, Erie's leaders and the corporate lawyers sat down at the table. What resulted, on Aug. 28, 2012, were Colorado's first memorandums of understanding (MOUs) that legally bound oil and gas operators in a particular jurisdiction to standards stricter than those required by the state. The *Denver Post* called it "a thoughtful step forward."

"It's not as sexy as conflict, but it works a whole lot better," said Doug Hock, an Encana spokesman.

Since then, about a dozen local governments in Colorado have followed Erie's example. The MOUs seem to be working: oil and gas firms can get on with business while communities get their key concerns addressed. But how well MOUs actually work, what the tradeoffs are, and what elements of these agreements are most critical to their success, remain unclear. The Mines ConocoPhillips Center for a Sustainable West team led by Assistant Professor Jessica M. Smith is working to get to the bottom of MOUs, the goal being to share the best ideas and improve industry-community relations to everyone's benefit.

> "Even if you get all of the technical stuff right, it doesn't matter if you don't have the communities on board ... You need to have a social license to operate."
>
> *—Assistant Professor Jessica M. Smith*

There has been increasing friction between communities and oil and gas companies. Population growth has played a role: Erie's population has jumped from 1,500 to 21,500 in the past 20 years; Weld County's rose 52 percent in the past 15 years, to 278,000. For many, since the mid-2000s, the oil and gas boom spurred by hydraulic fracturing has brought drilling rigs closer to home.

It's big business: according to the Colorado Oil and Gas Association (COGA), an industry group, Colorado hosted 53,400 active wells as of April 2015 – 22,318 in Weld County alone. In 2012, the industry produced $9.3 billion in fossil fuels, employing more than 111,000 people at an average wage of $75,000, which was 50 percent higher than the state average. Landowners received another $614 million in royalty payments that year, COGA said.

The state, via the Colorado Oil and Gas Conservation Commission (COGCC), regulates the industry with a range of measures related to minimum drilling setbacks (at least 500 feet from an occupied building), noise, air quality, water quality and other areas. But following those measures to the letter of existing law may not be enough anymore, as the drilling moratoriums demonstrate.

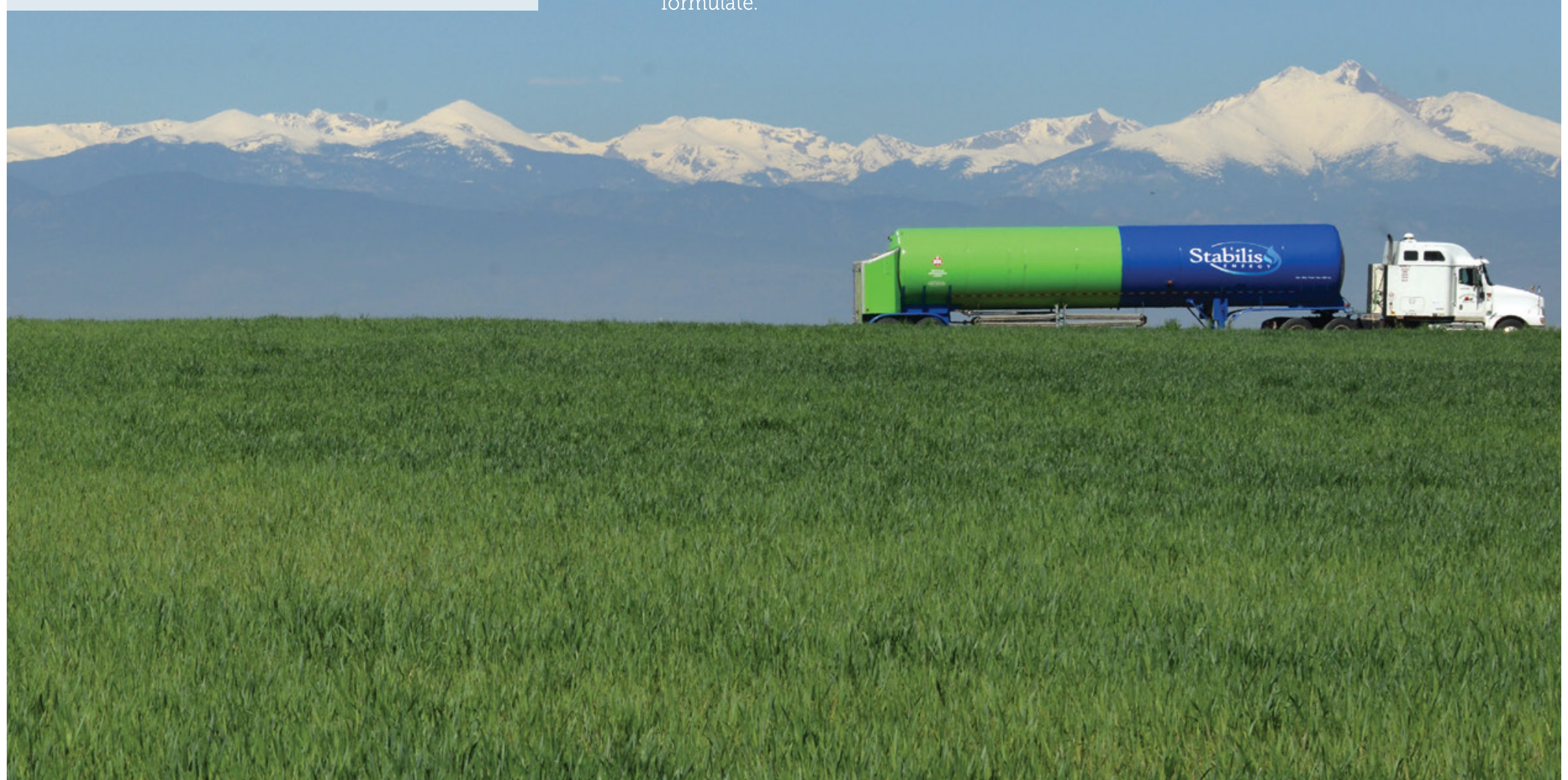
"Even if you get all of the technical stuff right, it doesn't matter if you don't have the communities on board," Smith said. "You need to have a social license to operate."

Smith, an anthropologist whose specialty is corporate-community relations, set out in late 2014 to better understand how MOUs contribute to that social license. Her research has taken her to mines in Wyoming, Washington and Peru. The driving interrogative throughout, she said, has been "How do you get from a position of community skepticism, if not outright conflict, to having successful industry-community relations?"

Smith enlisted Mines master's student Skylar Zilliox, now a ConocoPhillips Center graduate fellow; and undergraduate petroleum engineering student Austin Shaffer, a ConocoPhillips Center undergraduate scholar.

Zilliox, who earned her undergraduate degree in physics at Mines following a liberal arts degree from St. John's College in Sante Fe, was raised by oil and gas industry engineers.

"I was a bit conflicted," she said. "I was familiar with the industry and obviously some environmental issues around it, and also issues around public perception and stakeholder relationships — a lot of complex questions I hadn't found a way to formulate."



The MOU project, Zilliox said, is an opportunity to synthesize her technical and liberal arts backgrounds and to refine her sense of the business she grew up in. Shaffer, a junior who also runs track at Mines, said he became interested in social issues associated with oil and gas during a summer internship in Arkansas, where he learned about contracts with local landowners.

"Being a ConocoPhillips scholar, I'm open to anything that has to do with protecting water and other environmental mitigation," he said.

The team decided to focus on a comparative study of two Weld County communities, one with oil and gas MOUs, the other without them. They chose Erie and Firestone, neighbors on opposite sides of Interstate 25. The towns are similar in terms of population and demographics, and they had seen 2,000 wells permitted within their combined boundaries in the past five years, Shaffer said.

Among the provisions in Erie's MOUs with Encana and Anadarko included maximizing equipment and wellhead setbacks from occupied buildings and residences; notifying landowners within a half mile of drilling operations; submitting plans for noise, light and dust mitigation as well as traffic management; using steel-rim berms around tanks and separators instead of sand or soil; and preserving air quality with multistage pressure separation and vapor recovery units.

Shaffer mapped well locations and scoured the COGCC complaint database as Zilliox set off to interview town board members in Erie. From 2010 through November 2014, Shaffer found resident complaints in Firestone — touching noise, air quality, esthetics, property damage and other things — to vastly outnumber those in Erie (47 versus just two). The reasons, Smith said, weren't clear.

"It could be that they didn't have complaints," Smith said. "Or it could be that Erie was able to come to agreement on an MOU because people in general were more supportive of industry, or that they had other avenues to interact with industry."

Smith added that she's interested in the impact of MOUs on public trust of government and, in turn industry. "When people distrust government, they have a very low opinion of the natural gas industry and hydraulic fracturing," she explained.

But in December 2014, an Encana drilling rig just outside Erie's affluent Vista Ridge subdivision produced 47 complaints, most having to do with noise. The ensuing uproar led Erie's Town Board to vote on a moratorium in January; it was defeated. The MOUs with Encana and Anadarko, which had been in the process of renegotiation for months, were ongoing as of April 2015. It all underscored the challenge of doing academic research on history that's still playing out.

"You know, everything's more complicated than you initially think it is," Zilliox said.

Regardless, MOUs seem here to stay in Colorado. Hock, the Encana spokesman, said they're a good way to address concerns of the community while allowing companies to move forward with operations.

"By implementing an MOU-type agreement, we can meet the needs of all stakeholders," Hock said. "That's really the end goal of all this."

Matt Lapore, the COGCC director, added that MOUs take the issue of state versus local control off the table. Companies agree to stricter regulations as a part of their COGCC-issued drilling permit, and it's thereby enforceable by the state without the local regulations stepping on state jurisdiction.

"Do we think it's a good idea? Absolutely," Lapore said. "We really think it's a great tool."

The tool itself is evolving, Lapore said: MOUs done since 2012 by Arapahoe County, Adams County, Broomfield and elsewhere tend to be more specific, in their detailing of required management practices.

Smith's Mines team will be taking note as they work to understand — and ultimately disseminate both through academic papers and in ways accessible and useful to industry and local government — the impact MOUs have on communities, industry, and state and local politics.

Encana Oil & Gas

A message from John Poate

It certainly has been a transition for me to step down as vice president of research after nearly 10 years at Mines. It has been a wonderful journey to be part of the remarkable growth in research at this unique institution.

One of the delights has been shepherding the launch and production of this magazine. A great feature has been this guest column that closes the magazine. We are proud, and lucky, to have had columns written by some towering figures in the U.S. scientific and engineering worlds. They are, in chronological order, Norman Augustine (2008, retired chair of Lockheed Martin and chair of the National Academy Report "The Gathering Storm"), Ken Salazar (2009, former U.S. Senator and Secretary of the Interior), Daniel Yergin (2010, chair, Cambridge Energy Research Associates and prize winning author), Marcia McNutt (2011, editor of *Science* and former director of the U.S. Geological Survey), Craig Barrett (2012, former chair of Intel), Robert Birgeneau (2013, former chancellor of UC-Berkeley and head of the Lincoln Project), and Alex King (2014, director of the Critical Materials Institute and former director of Ames Laboratory). In each piece, the common theme has been passion for research and education and the desire to maintain U.S. scientific and economic leadership. In my column, I will address this theme with vignettes from Mines.

PIONEERING RESEARCH

A central challenge driving much research is that of climate change and environmental degradation. Solutions will almost certainly depend on scientific and technological advances in sustainable and clean energy. Mines has played a pioneering role in the energy world and in at least two key developments that have taken decades to mature.

Extraction of natural gas from nanoscale pores in shale or rocks has transformed the energy agenda of the U.S. To quote Daniel Yergin regarding the shale gas revolution from his book, "The Quest": It is dramatically changing the competitive position of everything from nuclear energy to wind power. It has also stoked, in a remarkably short time, a new environmental debate.

Mines has long been a leader in the scientific advances of reservoir characterization and the engineering challenges of hydraulic fracturing. The Potential Gas Committee, headquartered at Mines, charted and predicted this remarkable revolution in 2008 among some outside skepticism. The burning of shale gas has led to a substantial reduction in U.S. carbon dioxide emissions by replacing coal-burning power stations.

But shale gas is not the ultimate solution.

Electrical generation from photovoltaics is now playing an ever-increasing role in the clean energy portfolio. In its commitment to clean energy, Apple just announced it will power a substantial portion of its California operations from a 130 megawatt First Solar photovoltaic plant using cadmium telluride thin film technology. This is a major development in clean energy. Mines faculty, graduate students and the Energy Department's National Renewable Energy Laboratory played a crucial role in the early days of this technology in understanding the physical and chemical properties of cadmium telluride and developing a thin film deposition and manufacturing technology.

John Poate receives an honorary doctorate from President Emeritus Bill Scoggins during the spring 2015 commencement ceremony.

JOHN POATE
Emeritus Senior Vice President, Colorado School of Mines

- Fellow of the American Physical Society and the Materials Research Society
- Editor of *Applied Physics Reviews*
- Earned a PhD in Nuclear Physics from Australian National University
- Headed the Silicon Processing Research Department at Bell Laboratories
- Former dean of the College of Science and Liberal Arts at New Jersey Institute of Technology
- Served as president of the Materials Research Society and chair of the NATO Physical Sciences and Engineering Panel
- Chairs Lawrence Livermore National Laboratory review committees and is on the board of the National Renewable Energy Laboratory

These stories illustrate the impact Mines has played in the energy world. That impact will continue with the next generation of photovoltaics and enhanced geothermal in the subsurface world. It is difficult to identify a U.S. university that has more technical expertise than Mines in the energy and extractive industries. Our expertise in mining technologies is greatly bolstered by our strength in mineral economics. As Alex King pointed out in his column last year, understanding the economics and supply chain of critical minerals is an essential component of our national security. The same can be said of energy security and the newly formed Payne Institute for Earth Resources at Mines that will also focus on energy economics and policy analysis to complete the portfolio in this policy arena.

HANDS-ON EDUCATION

There has been much publicity over the past year or so on the role and impact of online learning at U.S. universities. While online learning will have an impact, much of the discussions have missed the mark in terms of U.S. research universities. My sense from watching Mines undergraduates is that a highlight of their educational experience is participating in hands-on research or design projects with faculty. Such an experience with faculty and other students cannot be carried out in the virtual world. A more pressing issue, as discussed by Robert Birgeneau, is the privatization of the public research universities, principally through loss of state funding. These great U.S. institutions have been the backbone of our engineering and research infrastructure. We have a real problem if the transition to privatization leads not only to the diminution of these universities but also lack of access for underprivileged students.

Apart from these challenges, the future of research at Mines is very bright. We are in the right space at the right time, focused on earth, energy and the environment. Mines is poised to reach the top tier of U.S. universities where research stature is the determinant.

—John Poate

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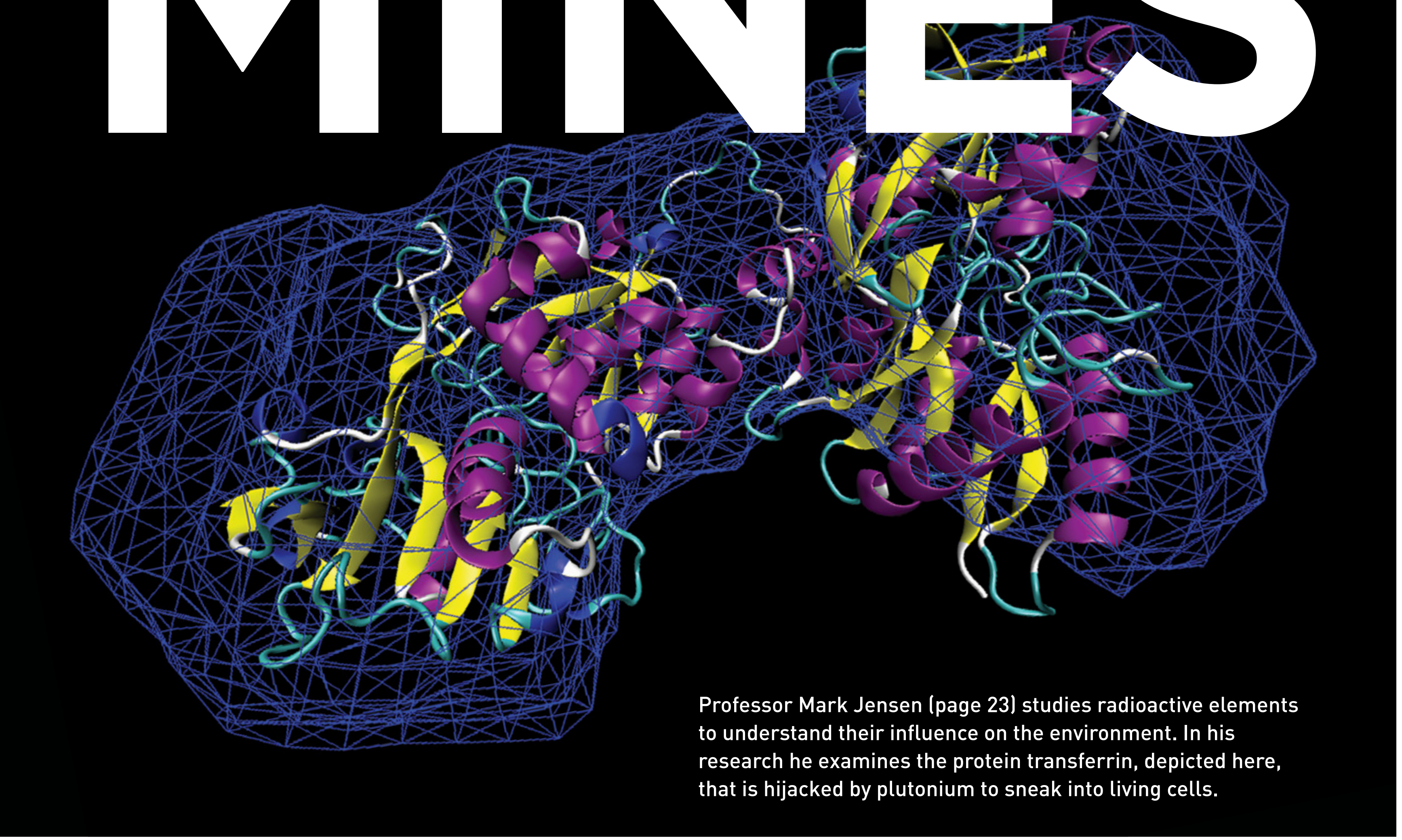

Professor Mark Jensen (page 23) studies radioactive elements to understand their influence on the environment. In his research he examines the protein transferrin, depicted here, that is hijacked by plutonium to sneak into living cells.

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