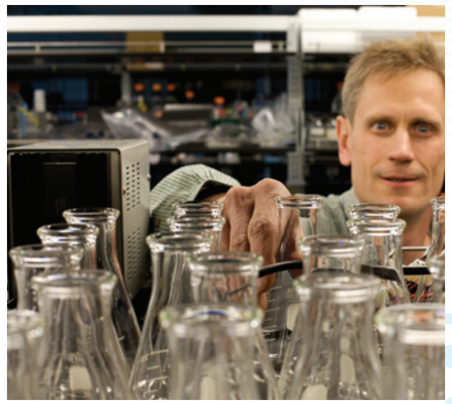
Colorado School of Mines

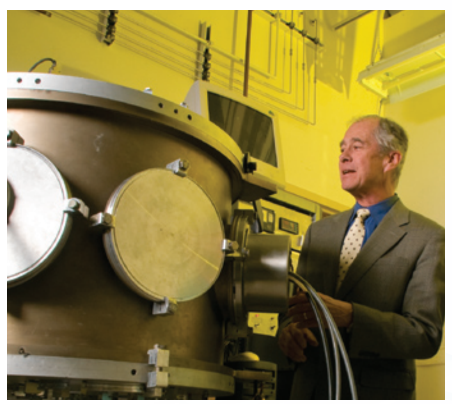
ENERGY AND THE EARTH

GLOBAL RESEARCH 2009

Colorado School of Mines
ENERGY AND THE EARTH
GLOBAL RESEARCH 2009

Contents


26


44


35


38

Features

Dr. M.W. Scoggins
Colorado School of Mines President

Dr. John M. Poate
Vice President for Research and Technology Transfer

Colorado School of Mines
1500 Illinois Street
Golden, CO 80401

303-273-3000 or 800-446-9488

www.mines.edu/energyandtheearth

EDITORIAL
Karen Gilbert
Public Relations Specialist, Editor

Brenda Gillen/Writing Matters, LLC
Energy and the Earth Writer and Editor

Marsha Williams
Director of Integrated Marketing Communications, Editor

ART DIRECTOR
Craig Korn
VeggieGraphics

PHOTOGRAPHY
Thomas Cooper
Lightbox Images

PRINTING
American Web
CPM Number #40065056

GLOBAL RESEARCH at Colorado School of Mines

To tell the full story of the strength and diversity of research at Mines, we need more space than a 48-page magazine allows. But we are proud to provide this sampling of the research conducted not only in Golden, Colo., but by Mines researchers on every continent around the globe.

This school plays a unique role in the educational fabric of Colorado and the nation. We are the only scholarly institution whose articulated mission is to enhance understanding of the earth, energy and the environment. This focused mission has gained us international prominence since our founding in 1874. Indeed the school is probably better known overseas than in the U.S. We continue to drive our international presence and research collaborations, some of which are highlighted throughout the magazine. The research activities of our faculty and students span the globe.

Our earth-energy related portfolio of research is unparalleled in terms of covering the whole enterprise. Environmental research focuses quite naturally on energy-related water issues and water sustainability in the Rockies. I should emphasize that to fulfill our charter as a first-rate research university, we encourage a full range of scholarly activities. Last year, for example, our physicists were part of an international research team that detected the spectrum of cosmic rays with energies greater than 10^{20} eV at their observatory in Argentina. This groundbreaking discovery has excited astrophysicists around the world, and you can read about it in this magazine.

It has been a great year for research growth at Mines. The school is ideally positioned with its focus on the earth, energy and the environment. Global warming is real but the solutions to curtailing carbon dioxide emissions can only be realized with a true understanding of the world's energy portfolio. For example, natural gas would appear to be a realistic bridge to a carbon free future, but can we extract sufficient quantities in an environmentally friendly fashion?

Subsurface sequestration appears to be an ideal path to carbon dioxide mitigation. In fact, Mines' geophysicists were some of the key players in the first demonstration some 10 years ago of the feasibility of carbon dioxide sequestration in a Canadian reservoir. But can such technologies be applied economically and without risk on a global scale? There are myriad important questions for both conventional and renewable energy sources. We are in the thick of this research working with industry and national laboratories, such as the National Renewable Energy Laboratory (NREL), Livermore and Sandia, to get to the bottom of many of these important scientific and technological issues. Notable research highlights include the following, which are detailed in the magazine:

- A major National Science Foundation (NSF) award for research in next generation photovoltaics, fuel cells and hydrogen storage in clathrate structures
- The newly installed high performance computing cluster, focused on energy research
- Education initiatives that focus on energy and environmental issues including a major NSF award for graduate education
- Research into unconventional (tight and shale) gas, funded by the Research Partnership to Secure Energy for America

Critical to the success of our research agenda is the ability to attract top-notch faculty. This year's hires — with a particular focus on the biosciences — are outstanding, and we're pleased to introduce some of them to you within these pages.

You will also see a message in this magazine from U.S. Secretary of the Interior Ken Salazar. His statement is particularly important to Mines. The Secretary is a dedicated advocate of sustainable energy and stewardship of the environment. As a U.S. Senator he drove the formation of the Colorado Renewable Energy Collaboratory, a partnership of NREL, Mines, the University of Colorado-Boulder and Colorado State University. A major goal of the Collaboratory was to strengthen NREL's ties with the Colorado research universities and attract industry and jobs to Colorado. This enterprise has been a great success on the research front and was instrumental in helping attract ConocoPhillips' new research center to the Front Range. Another major success for the Collaboratory was partnering with MIT and Stanford to win the management bid for NREL with Battelle and the Midwest Research Institute.

So the future for the research agenda at Mines is bright. We are in the right place at the right time with a very talented faculty and student body. Our most valuable products are our students, who will continue to be major contributors to the world of science and engineering. However, as we all know, the country is facing turbulent economic times. Public institutions such as Mines are under severe financial stress at both the undergraduate and graduate levels. We will need your continued support of our talented students and critical research endeavors. I trust that the research and education themes highlighted here will help guarantee your support.

As I mentioned earlier, I wish we could cover all the themes and all the outstanding individuals associated with Mines. They are the reasons our research is known, respected and sought by institutions around the world.

John Poate

Dr. John M. Poate
Vice President for Research and Technology Transfer

John Poate is an internationally recognized expert in science and technology with a distinguished career in academia and industry. He obtained his PhD in Nuclear Physics at the Australian National University. Most of his research career was pursued at Bell Labs where he headed the Silicon Processing Research Department. Since then he has served as Dean of the College of Science and Liberal Arts at New Jersey Institute of Technology and Chief Technology Officer of a semiconductor capital equipment company. His awards and distinctions include Fellow of the American Physical Society, President of the Materials Research Society, Chair of the NATO Physical Sciences and Engineering Panel, winner of the John Bardeen Award of the Metallurgical Society, and appointment to the inaugural class of Fellows of the Materials Research Society. He is on the board of the National Renewable Energy Laboratory.

John Poate is pictured in front of "Yosemite," an undated oil painting by Albert Bierstadt, known for the western American landscapes he painted in the mid-1800s. The painting was donated to Colorado School of Mines in 1938 by Mr. and Mrs. Benjamin Briscoe and currently is on loan to the Denver Art Museum.

Global **RESEARCH**

They're frequent fliers. From continent to continent—time zone to time zone, Mines faculty members travel to collaborate with top researchers around the world. This map represents some of the projects and places where Mines faculty have active research projects important to all society.

Tom Davis/Reservoir Characterization Project
Projects: **oil and gas petroleum reservoirs**
Rulison Field, Colo.; Guymon, Okla.; Alberta and Saskatchewan, Canada

Mark Lusk/Salish Kootenai College partnership
Projects: **computer research, oil creation from forest products**
Pablo, Mont.

Junko Munakata Marr, Environmental Science and Engineering
Project: **microorganisms' effects on environmental cleanup**
Laramie, Wyo.; Bangkok, Thailand; Sendai, Japan

Carolyn Koh/Center for Hydrate Research
Projects: **hydrogen storage, better flow of extracted fuels**
Paris; Trondheim, Norway; Osaka, Japan; Tehran, Iran; Gachibowli, India; Delft, Netherlands; Daedeok Science Town, Daejeon, South Korea

David Pyles/Chevron Center of Research Excellence, Department of Geology and Geological Engineering
Projects: **reservoir management and modeling**
Southern Pyrenees, Spain; western Ireland; southern France; southern California, southern Wyoming

Craig Taylor/Renewable Energy Materials Research Science and Engineering Center
Projects: **photovoltaic devices, fuel cells, clathrates for hydrogen storage**
Sydney, Australia; London

David Matlock and John Speer/ Advanced Steel Processing and Products Research Center
Projects: **steel advancements for auto industry, bridges, buildings, manufacturing**
Seoul, South Korea; Chennai, India; Luxembourg; Stockholm, Sweden

Jeff Andrews-Hanna, Geophysics
Projects: **tectonics, geodynamics, hydrology, Mars climate, Mars and Moon crusts**
Cambridge, Mass.; St. Louis, Mo.; Pasadena, Calif.; Boulder, Colo.

Keith Neeves, Chemical Engineering
Project: **blood clots' formation and dissolution**
Denver; Oak Ridge, Tenn.

Irene Polycarpou, Mathematical and Computer Sciences
Projects: **computer science education, energy research**
Aurora and Adams Counties, Colo.; Miami.

Yu-Shu Wu, Petroleum Engineering
Projects: **petroleum reservoirs, nuclear waste disposal, carbon dioxide sequestration**
Berkeley, Calif.; Beijing and Daqing, China; Herndon, Va.

John Scales, Physics
Projects: **waves for astronomy, materials science, geophysics, communication and remote sensing, landmine detection**
Boulder, Colo.; White-River Junction, Vt.; Bar-Ilan and Haifa, Israel; Paris and Grenoble, France

Fred Sarazin and Lawrence Wiencke/Pierre Auger Observatory
Project: **astroparticle physics research**
Prowers County, Colo. (pending); Malargüe, Argentina

Ryan Richards, Chemistry
Projects: **nanotechnology, catalysis, green chemistry**
Los Angeles; Madrid, Spain; Paris; Bucharest, Romania; Bremen, Germany; Novosibirsk, Russia; Wuhan, China

André Revil, Geophysics
Projects: **rocks and soils, oil and gas**
Mt. Princeton, Colo.; Mt. St. Helen, Wash.; Berkeley, Calif.; Boise, Idaho; Oak Ridge, Tenn.; Aeolian Island, Italy; Aix en Provence and Grenoble, France; Berlin; Syabru-Bensi, Nepal; Taupo, New Zealand

James Ranville, Chemistry and Geochemistry
Project: **environmental impacts of nanotechnology**
Blackhawk and Rifle, Colo.; Hanover, N.H.; Vicksburg, Miss.; Aveiro, Portugal; Adelaide and Sydney, Australia; Seoul, South Korea; Santiago and Copiapo, Chile

Matthew Posewitz, Chemistry and Geochemistry
Project: **microorganism biodiesel**
Boulder, Colo.; Palo Alto, Calif.; Princeton, N.J.; Bozeman, Mont.; Salt Lake City; Manoa, Hawaii

Ning Lu, Engineering
Project: **landslide prediction**
Seattle; southern California; Boulder and Nederland, Colo.; Black Mesa, Ariz.; Utah-Arizona border; Perth and Melbourne, Australia; Ya'an and Allao Shan, China; Busan, Korea

Robert Kee, Engineering
Project: **computer simulations to advance fuel cell technology**
Pasadena, Calif.; College Park, Md.; Chicago; Broomfield, Colo.; Rochester, N.Y; Karlsruhe, Germany

Murray Hitzman, Geology and Geological Engineering
Project: **mineral deposits**
Queensland and Tasmania, Australia; Lubumbashi, Congo; Kitwe, Zambia; Mauritanian Desert, Namibia

Jörg Drewes, Environmental Science and Engineering
Project: **recycling impaired water to augment freshwater supplies**
Berkeley, Calif.; Houston; Las Vegas; Los Angeles; Orange County, Calif.; Denver; Aurora, Colo.; Argonne, Ill.; Arizona; Rocky Mountains; Sydney, Australia

Tina Gianquitto, Liberal Arts and International Studies
Project: **evolutionary theory's impact on women reformers**
San Marino, Calif.; Cambridge, Mass.; Cambridge, London and Manchester, England

Graham Davis and Alexandra Newman, Division of Economics and Business
Projects: **mineral and energy extraction**
Berkeley, Calif.; Argonne, Ill.; Kiruna, Sweden; Santiago, Chile; Brisbane, Australia

Kadri Dagdelen, Mining Engineering
Project: **mathematical methods to improve mining projects**
Elko, Nev.; Morenci, Ariz.; Hibbing, Minn.; Dome and Ontario, Canada; Tarkwa, Ghana; North Mara, Tanzania; Yanachocha, Peru; Antafagasta, Chile; Izmir, Turkey

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

Microorganism research to improve environment


Mines PhD candidate Megan Smith, left, and Professor Junko Munakata Marr inspect soil columns designed to investigate interactions between microorganisms and polymers used for flow control.

Cleaning contaminated groundwater, removing nutrients from wastewater, generating methane from coal — these are just a few of the applications in which Junko Munakata Marr's microorganism research could help improve life on Earth.

Marr, an environmental science and engineering professor at Mines, said there is a lot to learn from microorganisms and many ways they can help improve the environment.

"We have lots of contaminated groundwater in the U.S., so our work on cleaning it up could make that water available for use — this is a particularly pressing resource issue in water-limited areas such as the southwestern U.S.," Munakata Marr said. "Nutrients such as nitrogen are an issue in waste streams worldwide, so we're interested in microbial removal of nutrients both in large centralized treatment plants as well as in distributed treatment systems, which are potentially more sustainable."

Additionally, she is working with researchers at the University of Wyoming and the U.S. Geological Survey on a coal project.

"Energy is clearly an issue in this country and we have lots of coal, so the coal project could help energy security in the U.S.," she said. "Our fundamental study of the microorganisms involved represents only the first step on a long path in that direction."

Her recent research efforts have gone global. Munakata Marr spent five months of a recent sabbatical studying nutrient removal in wastewater in Bangkok, Thailand, where many surface waters are green because they are so nutrient-rich. She also spent six weeks in Sendai, Japan, using DNA-based techniques to quantify microbes that clean up groundwater.

Mines collaborators include Linda Figueroa, Tissa Illangasekare, John McCray, Bob Siegrist and John Spear, who also work in the Environmental Science and Engineering Division.

The research projects are funded primarily through grants from government agencies, including the Department of Energy, the Environmental Protection Agency and the National Science Foundation, with some support coming from industry. Her international efforts have been recognized by the prestigious Fulbright Senior Scholar award and the Japan Society for the Promotion of Science Invitation Fellowship.

Mines announces new research projects with Abu Dhabi Petroleum Institute

Colorado School of Mines and the Petroleum Institute (PI) in Abu Dhabi recently signed an amendment to their long-term agreement to formalize opportunities and funding for joint research activities between the two institutions.

Mines will play a key role in research associated with upstream oil and gas recovery processes and technology. Initial projects are in the areas of reservoir characterization in carbonate geologies, multicomponent seismic exploration, corrosion resistance in high sulfur environments, and in instructional pedagogy.

"Mines has been the principal academic partner with the PI since its inception in 2001," said Nigel Middleton, senior vice president for strategic enterprises at Mines. "It offers undergraduate degrees in petroleum engineering, petroleum geosciences, chemical engineering, mechanical engineering and electrical engineering and a graduate program leading to master's degrees recently has been formed."

The PI enrolls approximately 1,100 students predominantly from the United Arab Emirates and with representation from 24 other countries.

The PI is governed by a board led by the Abu Dhabi National Oil Company (ADNOC), and with representation from ADNOC operating companies, BP, the Japanese Oil Development Company, Shell, Total and Mines.

Other partner universities include Johannes Kepler University in Linz and Montanuniversitat in Leoben, Austria, the University of Maryland, and the University of Minnesota.

Mines takes leadership role at NREL

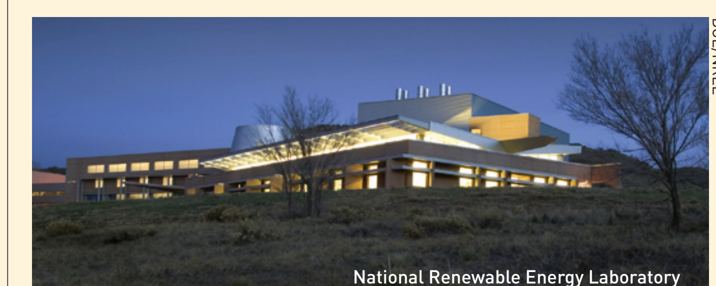
Colorado School of Mines' longtime partnership with the National Renewable Energy Laboratory (NREL) was strengthened last summer when Mines joined the agency's management team.

Located in Golden, Colo., NREL is the U.S. Department of Energy's (DOE) primary laboratory for energy efficiency and renewable energy research and development. The laboratory is dedicated to finding new renewable ways to power the nation's homes, businesses and automobiles.

In July 2008, the DOE selected the Alliance for Sustainable Energy (ASE) to manage NREL. ASE is a limited partnership owned and operated by two nonprofits — the Midwest Research Institute and Battelle, and both have managed NREL jointly for the past 10 years.

Mines is represented on the Alliance's board of directors, along with other universities, including the University of Colorado-Boulder, Colorado State University, the Massachusetts Institute of Technology and Stanford University.

Under the management of the Alliance, NREL anticipates developing global partnerships with academic researchers and industry leaders in efforts to drive innovations in market-relevant technology. While the benefits of these partnerships are far-reaching, NREL Director Dan Arvizu said Colorado's Front Range has the unique potential of becoming the Silicon Valley of renewable energy.


DOE/NREL
National Renewable Energy Laboratory

"Moving the new energy economy forward is going to require teamwork between educational institutions like Colorado School of Mines, NREL and private industry," said Arvizu. "Colorado has a formidable lead over many other states when it comes to renewable energy."

The three Colorado schools in the Alliance also are partners with NREL in the Colorado Renewable Energy Collaboratory, a renewable energy research consortium.

"Mines has enjoyed, from the earliest days, a very close working relationship with NREL, which has produced some great science and technology. As part of the executive team of ASE we are looking forward to bigger and better things in the critical areas of sustainable energy," said John Poate, vice president of research and technology transfer at Mines and ASE board member.

Mines presents "Global Energy Challenge"

istockphoto

In an effort to educate the public about the country's energy challenges, Mines W.M. Keck Distinguished Professor Roel Snieder developed "The Global Energy Challenge," an informational public lecture focused on energy issues and the opportunities associated with the energy industry.

According to Snieder, a geophysics professor, the presentation "sketches the tension between increased energy demand, peak oil, the associated challenge in curbing climate change, and actions that we can take towards a sustainable energy system."

The lecture debuted in January 2008 and has been delivered more than 60 times. It has been well received by audiences ranging from K-12 to college students, and by community members in service organizations such as Rotary clubs.

Snieder developed the presentation while working for the Global Climate and Energy Project at Stanford University.

"The presentation gives ideas for positive action that teachers, students, businessmen, consumers and citizens can take to deal with our energy challenges and turn them into opportunities," said Snieder.

The presentation is available for download at www.mines.edu/~rsnieder/Global_Energy.html.

ConocoPhillips, Mines pursue clean energy technologies

A $5 million research agreement sponsored by ConocoPhillips is helping researchers from Mines, the University of Colorado-Boulder (CU), Colorado State University (CSU) and the National Renewable Energy Laboratory (NREL) develop new ways to convert biomass into low-carbon transportation fuels.

The Colorado Center for Biorefining and Biofuels (C2B2), a research center of the Colorado Renewable Energy Collaboratory (a partnership formed in 2007 to conduct research at Mines, CU, CSU and NREL) received the research funding in 2008. As C2B2 continues to develop new biorefining technologies and biofuels, the technologies will be transferred to the private sector.

"ConocoPhillips' collaboration with C2B2 offers a unique opportunity to combine the technical strengths of the member institutions with ConocoPhillips' spirit of innovation to drive discovery of the next generation of transportation fuels," said Stephen Brand, ConocoPhillips senior vice president of technology. "We look forward to working with C2B2 to create new forms of clean energy."

Since its inception, C2B2 has sought to partner with small and large businesses. In addition to ConocoPhillips, C2B2 now counts more than two dozen businesses as partners, including Archers Daniels Midland, Chevron, Dow Chemical, General Motors, Kimberly Clark, Shell Global Solutions, Suncor Energy, Valero and more.

"ConocoPhillips played a key role in the formation of C2B2, and ConocoPhillips was determined to fund the first sponsored research with C2B2," said David Hiller, executive director of the Collaboratory. "We're grateful to ConocoPhillips for its support, and we're proud that we have earned the trust of ConocoPhillips and other major players in the biorefining and biofuels sector."

Mines anticipates the partnership with ConocoPhillips will continue to advance research and create jobs as the corporation announced early in 2008 plans to build a training and new energy research center in Broomfield, Colo. — less than 30 miles from the Mines campus.

"We are in the deconstruction phase now, which will continue through the end of the year. The opening date is still to be determined, but likely in 2013," said Tracy Harlow, ConocoPhillips spokeswoman.

More Petroleum Industry Research Partners

Abu Dhabi National Oil Company
Anadarko Petroleum Corporation
BP
Bill Barrett Corporation
Chevron Corporation
ConocoPhillips
EnCana Corporation
ExxonMobil Corporation
Halliburton
Marathon Oil Corporation
Oxy USA WTP LP
Schlumberger
Shell
Statoil ASA
Total
Whiting Petroleum
Williams

istockphoto

Mines puts focus on carbon, the chemical basis of all known life on Earth

A new center at Mines, the Colorado Carbon Management Center is dedicated to researching carbon management. Approved in 2008, the center is part of the Colorado Renewable Energy Collaboratory — a partnership with the University of Colorado-Boulder, Colorado State University, the National Renewable Energy Laboratory and the National Oceanic and Atmospheric Administration. The collaboratory also houses three other centers: the Colorado Center for Biofuels and Biorefining, the Center for Revolutionary Solar Photoconversion, and Collaborative Research for Education in Wind.

The collaboratory was established to address global energy issues, and the carbon center's role is to find methods to extract carbon and to store it underground. The carbon center is directed by Dag Nummedal, who also heads the Colorado Energy Research Institute at Mines. The center is funded by grants from the federal government and private industry. Other Mines faculty researchers in the center include John McCray from environmental science and engineering, Tom Davis from geophysics, and Ron Klusman from chemistry and geochemistry.

"The center is focused on all components of carbon's complex pathways on earth, yet with a clear mission not only to understand these pathways, but to apply that understanding in the design, management and operations of future energy systems," Nummedal said.

The amount of carbon on the Earth is constant, so carbon is obtained, used and disposed — a process known as the carbon cycle. For example, plants draw carbon dioxide out of the environment, use it to build biomass, and dispose of it in carbon respiration. The fact carbon plays such huge roles in all forms of life — on the earth, in the oceans and in the atmosphere — implies that for industrial society to be sustainable, humans must learn to adjust to the demands of the carbon cycle.

Nummedal said 50 years of basic research around the world have taught researchers how the carbon cycle works on temporal and spatial scales, but the challenge for the future is to engineer new approaches to transportation, energy supply, agriculture and infrastructure that operate in harmony with the way the earth recycles carbon, not in costly and futile attempts at ignoring or violating those natural laws.

He disputes the notion the rapidly advancing change from traditional fossil energy to renewable energy and clean fossil energy will be too expensive. History, he said, strongly suggests the opposite will be true. The industrial revolution, transportation revolution and the revolution in information technology all signify major changes in the understanding and use of energy — and all led to major economic booms.

"Why should this next transformation in the energy industry be any different?" he asked.

Colorado is uniquely positioned to lead and benefit from this transformation, relying on its deep, historical knowledge of the fossil energy industry, and banking on its recent leadership in renewable energy. Because carbon management is the central theme for all clean energy, hybrid technical expertise is particularly relevant.

"Colorado School of Mines has been focused on earth, energy and environmental research for 135 years, which gives us a head start over many, yet also a responsibility to help lead the world through these wrenching, yet overdue, changes in the earth's energy infrastructure," Nummedal said.

Multi-disciplinary graduate program receives grant for SmartGeo

A training program at Mines that enables PhD students to add real time, sensing and adaptive control capabilities to natural and engineered geosystems, such as tunnels, dams and bridges, got a boost last year from the National Science Foundation (NSF), which awarded it a five-year, $3 million grant as part of its Integrative Graduate Education and Research Traineeship (IGERT) program.

Through IGERT, administrators are creating cultural change in graduate education by establishing innovative models for collaborative research to transcend traditional disciplinary boundaries. They also aim to improve diversity in student participation and to help develop a globally engaged science and engineering workforce.

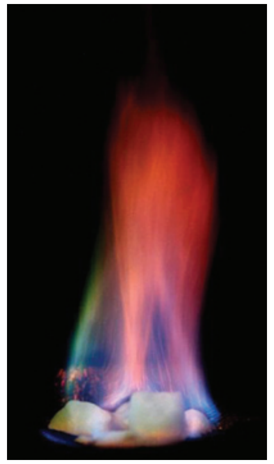
Using sensing, advanced data analysis techniques, adaptive modeling and decision support, SmartGeo researchers aim to create intelligent geosystems that sense their environment and adapt to improve performance. The program will pursue advances in geoconstruction operations (earthwork, tunneling, drilling), groundwater remediation, and geo-infrastructure monitoring (earth dams, levees, highways).

Key components of the Mines SmartGeo program include:

- A multi-disciplinary collaborative research team framework to foster development and interdisciplinary innovation in intelligent geosystem concepts
- A leadership and teamwork development program to train the next generation of geosystem leaders for industry, academia and government
- A PhD minor in social/environmental ethics and policy to broaden trainee understanding beyond the technical challenges to the social, environmental and political aspects of intelligent geosystems
- A self-paced cross-disciplinary technical course using modules in intelligent geosystems
- An internship with a government laboratory or industry in intelligent geosystems

TheSmartGeo program brings together students and faculty from nine academic disciplines at Mines to train the next generation of leaders in intelligent geosystems. The program is led by an executive committee comprised of professors Mike Mooney (engineering), Tracy Camp (mathematical and computer sciences), Dave Hale (geophysics), Linda Figueroa (environmental science and engineering), Carl Mitcham (liberal arts and international studies), and Deb Lasich, executive director of Mines' Women in Science, Engineering and Mathematics program. Visit http://smartgeo.mines.edu for more information.

Hydrate lab advances fuel storage research



Researchers at Mines' Center for Hydrate Research are working on new materials for hydrogen storage and on the flow assurance of extracted fuels. Their work will help the energy industry design deepwater facilities resistant to the formation of hydrates — ice-like solids that form blockages in pipelines. They are also working on developing new materials for fuel storage, including hydrogen and methane.

The center is headed by director E. Dendy Sloan, a Weaver Distinguished Professor and 2008 Albert Einstein Medal of Honor recipient, co-directed by Carolyn Koh and Amadeu Sum, and supported by David Wu, Matthew Liberatore and Joanna Lachwa-Langa.

Koh reports in the last few months the center has discovered two new important classes of materials for hydrogen storage.

They include a chemical clathrate hybrid technology that enables molecular hydrogen to be stored in clathrate cages — a lattice of water molecules that encloses molecules of trapped gas — and additional hydrogen to be obtained from the host framework. This provides the first proof-of-concept for a hybrid technology and opens up a whole new category of storage materials.

In a second breakthrough, the center successfully synthesized new hydrogen-clathrate hydrate compounds. Clathrate hydrate compounds are particularly attractive for hydrogen storage since they are 85 percent water.

"The major byproduct of this storage material on hydrogen gas release is water," Koh said.

This year the center will launch a kinetic and transport model that will be combined with an industrial standard multiphase flow simulator. Projects like these are of great interest to the center's in-house industry consortium, comprised of 12 energy and chemical companies.

A talented pool of students, postdoctoral associates and visiting professors come from all corners of the world to research three main application areas of gas hydrates: energy transportation, production and storage, and basic sciences. Currently the center is hosting representatives from Japan, Iran, India, the Netherlands and Korea.

Institute serves as gateway for energy projects

Over the next century, the convergence of increasing population and global economic development will present what could be the greatest challenge ever in managing the world's resources.

The Earth-Energy Institute (EEI) at Colorado School of Mines will be the single point of contact for industry and governmental agencies seeking access to Mines' energy-related expertise. The idea for the institute came about in spring 2008, and construction of a new laboratory and education and support facilities is slated for 2010. Tom Boyd, dean of graduate studies, has worked collaboratively with many others to envision EEI and its role in meeting energy challenges.

istockphoto

"In short, the Earth-Energy Institute will serve as an intellectual commons for coordinating and advancing research and educational activities related to Mines' energy mission and will facilitate connections to the breadth of resources available across the Mines campus," said Boyd.

The institute will address issues such as carbon sequestration; bioenergy, nuclear and geothermal energy production; extraction and use of unconventional fossil energy sources such as oil shale and hydrates; clean coal technologies; third-generation photovoltaics; impacts of resource extraction and power generation on water quality; and related social, economic and policy implications.

EEI will operate outside the boundaries of traditional department and division models and while it will develop new research, it also will promote and more effectively integrate the activities of Mines' existing research centers. The institute will provide:

- A physically contiguous infrastructure to support coordinated research endeavors
- A unified management and organizational structure designed to foster a rich interplay of ideas from diverse disciplines
- High-level advocacy, coordination and support for the development and financing of specialized research facilities and initiatives
- Streamlined management of currently fragmented industry relationships to maximize partnership opportunities
- A nucleus for academic activities that support the institute's mission

A goal of the institute is to foster a global and interdisciplinary perspective on energy production and distribution, resource development, the Earth and its environment and the intertwined policy and social license issues.

Boyd said that while traditional organizations are siloed, preventing relevant, interwoven solutions to multifaceted challenges, the EEI would take a new approach, one that encompasses a global and interdisciplinary perspective on science, technology, economics and energy policy.

The new Earth-Energy Institute will house Mines' activities associated with the Colorado Renewable Energy Collaboratory — a research partnership with the National Renewable Energy Laboratory, Colorado State University and the University of Colorado. Other potential partners include the National Center for Atmospheric Research and the U.S. Geological Survey.

Mines partners with tribal college in energy research and computing

Mines and Montana's Salish Kootenai College, an accredited four-year college tribally controlled by the Confederated Salish and Kootenai Tribes, have developed a promising partnership allowing the schools to jointly address difficult problems in energy science research and team up on high performance computing.

The collaboration began with research and instruction through the Golden Energy Computing Organization (GECO) — directed by Mines professor Mark Lusk — and now includes the Renewable Energy Materials Research Science and Engineering Center (REMRSEC) at Mines.

Salish Kootenai College, which offers a bachelor of science degree in computer engineering, is comprised of students representing some 107 federally recognized tribes.

NREL

The new energy science facet of the collaboration, initiated by Mines professor Andrew Herring, aims to develop a technique to create oil from forest products that can be directly used as a fuel or can be further processed into synthetic natural gas. Salish Kootenai College manages large tracts of forests and has a strong program in environmental engineering related to forest management, while Mines has an established program in chemical processing, making for a natural fit.

"The two schools have found that working together makes good sense for our students, faculty and the energy science community," Lusk said.

Lusk has made several trips to Montana, and Salish Kootenai students and faculty have also visited Mines. Last summer, five students and a professor from Salish Kootenai College came to Golden for training on systems administration.

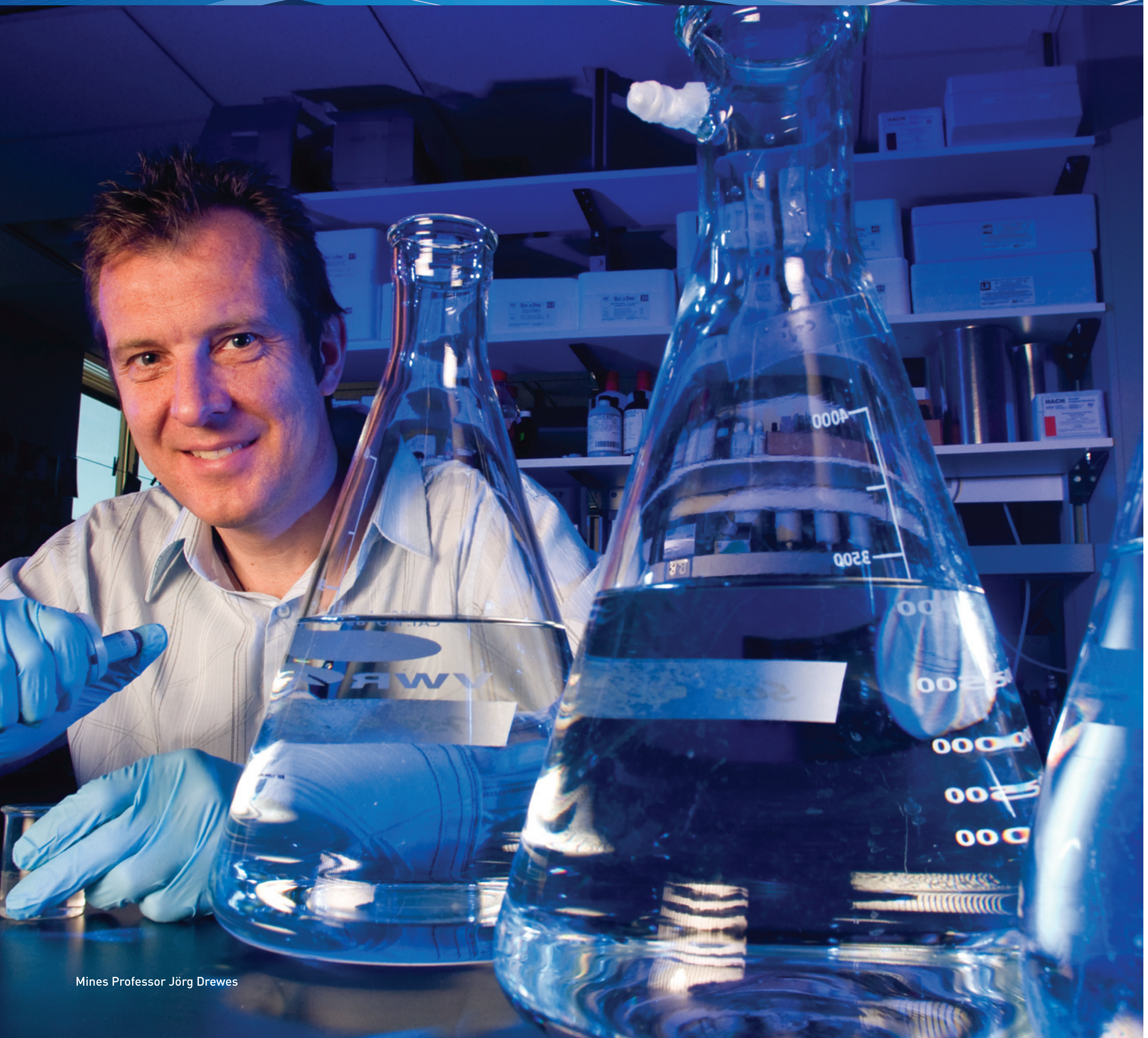
As Lusk noted, "just the care and feeding" of high performance computing clusters can be demanding. Interaction with and training of machine users also require that system administrators and network engineers know a lot about the science being carried out on their machines. On top of that, they need to set up job scheduling and perform endless research of their own to push the limits on machine performance. Salish Kootenai students received intensive training in each of these areas.

Mines is home to a supercomputer dubbed "Ra," an homage to the ancient Egyptian sun god. As one of the world's fastest computing clusters, it has 2,144 computer cores that can carry out complex scientific queries in a coordinated fashion — Lusk notes a laptop typically has just one or two such cores. With support from Mines, Salish Kootenai College students have refurbished their 32-core computer to set up a computing environment like the one Ra offers. Research investigations are running on both machines.

While the students were in Golden, the group took tours of the National Renewable Energy Laboratory and the National Center for Atmospheric Research to learn more about high performance computing at other energy science research facilities. Two of the students who visited in 2008 will be back during summer 2009 with three of their colleagues as participants in the REMRSEC Research Experience for Undergraduates (REMRSEC-REU).

The five Salish Kootenai College students will work with Mines students in a 10-week research program focusing on photovoltaics, fuel cells and energy storage systems. (See page 45 for more about REMRSEC-REU.)

Lusk, who also is an investigator in REMRSEC, said the organization is supporting the collaboration by providing $50,000 annually for six years for Salish Kootenai College. The funding currently supports five student scholarships, funding for faculty research time, and the financial backing that has made renovation of their computing cluster possible.



Mines Professor Jörg Drewes

Investigating untapped resources and new wastewater treatment processes

Turn on the TAP

Colorado, like many places in the West and throughout the U.S., faces growing concerns about available water. Although freshwater resources are completely allocated, population continues to grow and demand continues to rise. Meanwhile, uncertainties due to climate change create additional stress on available water resources. It's clear new approaches are needed.

Jörg Drewes, an associate professor of environmental science and engineering, is researching ways to safely use unconventional water resources, including municipal wastewater effluents, brackish groundwater and even water left over from natural gas operations.

"Municipal wastewater represents a drought-proof supply as long as we continue to take showers, flush toilets and do our laundry. The common practice is to treat this water to achieve water quality standards that are suitable for discharge to the environment. The obvious question is why not treat it to levels that can augment local drinking water supplies?" Drewes asked.

He said another untapped resource in the West is "produced water" from natural gas operations, the saline groundwater that is brought to the surface during gas extraction and is usually disposed into deep injection wells. Drewes believes after appropriate treatment, produced water could be beneficially used.

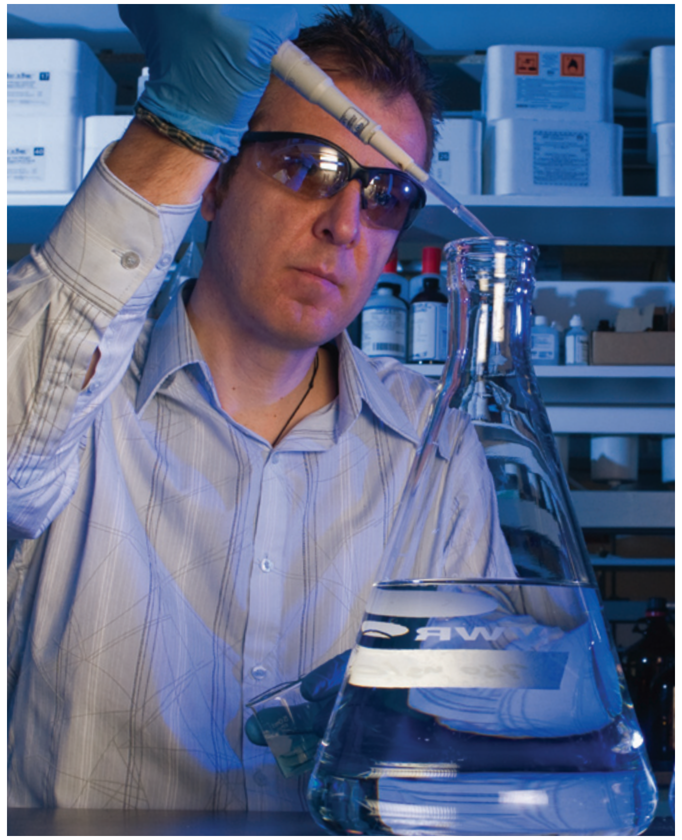
But many people are uncomfortable with the idea of reusing such water. Thousands of trace organic chemicals occurring at the parts-per-trillion concentration level — such as pharmaceutical residues, personal care products, endocrine disrupting compounds and household chemicals — are present in municipal wastewater. Not all of these chemicals are completely removed during conventional wastewater treatment, but with new treatment processes it can be safely used for human consumption.

Drewes is working on research to better understand the fate and transport of these chemicals in water treatment processes. He's developing predictive models that can be used for performance assessment of water treatment processes. The models are utilizing quantitative structure property relationships that consider the structure and properties of individual compounds and couple them with treatment process data.

This approach, Drewes said, not only simplifies analytical monitoring programs by identifying more meaningful compounds for performance assessment (among the thousands of compounds potentially present), but also offers certainty that treatment processes are working and providing safe, potable water. California and Australia have adopted this approach, developed at Mines, into their guidelines for drinking water augmentation with recycled water.

Besides augmenting freshwater supplies, Drewes' research is directed to the design and operation of more sustainable water treatment processes that achieve suitable water quality, while at the same time, use less energy and fewer chemicals and produce less waste. Local and regional municipalities throughout the world could benefit from the research, which is highly collaborative.

"The research we are doing — promoting reuse of municipal wastewater and brackish groundwater — provides certainty in common and novel treatment processes and thereby promotes the



implementation of these processes in a modern water infrastructure," Drewes said.

Research partners include universities, drinking water and wastewater utilities, national laboratories and environmental consulting firms. In Colorado, Drewes works with the City of Aurora, which is implementing a new drinking water treatment plant that utilizes natural and advanced treatment processes. He works with water utilities in Southern California, Nevada and Arizona to promote groundwater recharge with recycled water. And in Colorado, Wyoming, Montana, New Mexico and Utah, he works with the oil and gas industry to promote beneficial use of produced water from operations in the Rocky Mountain region. In Australia, he collaborates with colleagues at the University of New South Wales and water utilities using membrane-based treatment processes to recycle water for freshwater augmentation.

Many Mines students and faculty members are involved in the research, including Mark Eberhart from chemistry and geochemistry and Drewes' colleagues from environmental science and engineering, Tzahi Cath, John McCray, Pei Xu, Chris Higgins, John Spear and Robert Siegrist. Funding for the research comes from grants from the Water Research Foundation, WateReuse Foundation, Water Environment Research Foundation, Department of Energy (DOE), DOE/Research Partnership to Secure Energy for America and the Colorado Department of Public Health and the Environment; and industry support from Aqua-Aerobics Systems Inc., the Water Replenishment District of Southern California, and County Sanitation Districts of Los Angeles County.

Drewes is a National Academy of Sciences' National Research Council panelist, serving on the Assessing Water Reuse as a Means of Meeting Future Water Supply Needs committee. Last year, he earned the Outstanding Research Award from the Water Works Association's Rocky Mountain section. Previously, he earned awards in Arizona and Germany.

The Flatirons of Boulder, Colo., reflecting in a pond at dawn.

Women's letters reveal altruism as driver of evolution

Dear MR. DARWIN

Tina Gianquitto teaches courses in American literature at Mines, but her current research focuses on works that have never been published. An associate professor in the Liberal Arts and International Studies Division, Gianquitto is intrigued by late 19th century women reformers and their correspondence with naturalist Charles Darwin.

The reforms those American women championed included suffrage, animal protection, labor law reform and poverty reforms. Many of the women who wrote to Darwin in England supplied him with information he incorporated into his later books, written after his seminal work about evolution in 1859, *On the Origin of Species*. Others wrote to challenge Darwin's ideas, especially his representation of women's intellectual abilities.

Gianquitto explained part of her research involves examining the notion of nature in a post-evolutionary landscape.

"After Darwin, people began to understand the natural world as a web of relationships, where action in one realm produced reactions in others. Species co-evolved; communities of individual organisms co-adapted for mutual benefit. This understanding of nature as a web of complex interaction provided a new language for those looking to re-imagine human communities," Gianquitto said.

In part, the theory of evolution freed women from their prior roles in society and offered support for those fighting for the rights of the poor and oppressed. She said her focus on Darwin is different from the "social Darwinism" or the survival of the strongest over society's weaker members. Instead, Gianquitto is interested in displaying a lesser-known narrative of evolution.

"This narrative, supported by many of the women I study, focused on altruism, on the 'moral sense' developed for the good of the community as a whole, as a key driver of evolution," she said.

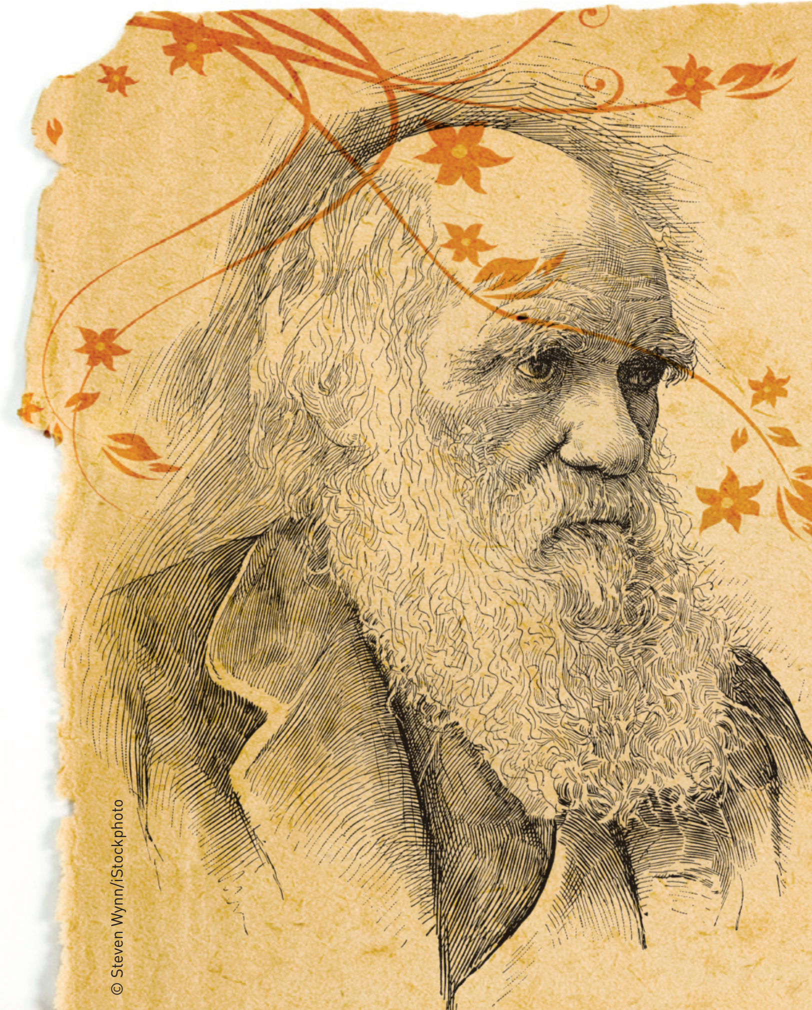
The focus on women is important to the cultural understanding of evolution, and Gianquitto sees it as having a broad impact on several communities. It will benefit the community of scholars who study the history of science, women's studies and the history of Darwinism, but she hopes to reach a broader general audience.

"Darwin and the impact of evolutionary theory remains a compelling topic for many. This story — of women's response to and use of evolutionary theory — is one that has not been told."

Gianquitto works with a number of archives and communicates regularly with other literary scholars. Her research has taken her to Cambridge, London and Manchester, England; the Huntington Library in San Marino, Calif., and to Harvard University, Cambridge, Mass. Last summer, she was in England reading through boxes of handwritten correspondence to and from Darwin.

Her research is supported by fellowships including the National Endowment for the Humanities Fellowship; the American Council of Learned Societies Charles A. Ryskamp Fellowship; and the Dibner History of Science Fellowship from the Huntington Library.

She has published several articles and a book, *Good Observers of Nature: American Women and the Scientific Study of the Natural World*, 1820-1885 (University of Georgia Press, 2007). Her book in progress is tentatively titled *Dear Mr. Darwin: Women, Evolution, and Radical Social Reform*.



Professor Tina Gianquitto kayaking in the Harriman Fjord in Alaska.

Researchers collect data from subatomic particles

High **ENERGY**

Astroparticle physics researchers and Mines professors Lawrence Wiencke and Fred Sarazin are members of the Pierre Auger Collaboration — a group using the world's largest observatory to study the highest energy subatomic particles in the universe, ultra-high energy cosmic rays (UHECR).

To say these particles are energetic is an understatement: They can carry more than 10 million times more energy per particle than can be reached at the largest particle-accelerator laboratories on Earth.

Although the existence of these particles, which are believed to be protons or atomic nuclei, has been known for more than 40 years, Wiencke said there are many unanswered questions: Where do they come from? How do they attain these energies? What types of particles are they? When they hit the earth's atmosphere with these extreme energies, do they interact in ways that cannot be explained using the current knowledge of particle physics?

"The Pierre Auger Southern Observatory, located in Argentina, is the world's largest UHECR detector and it is collecting fascinating data," said Wiencke. "However, this detector only views the southern sky and the data are telling us that we need a much larger instrument to resolve the question of where these particles originate."

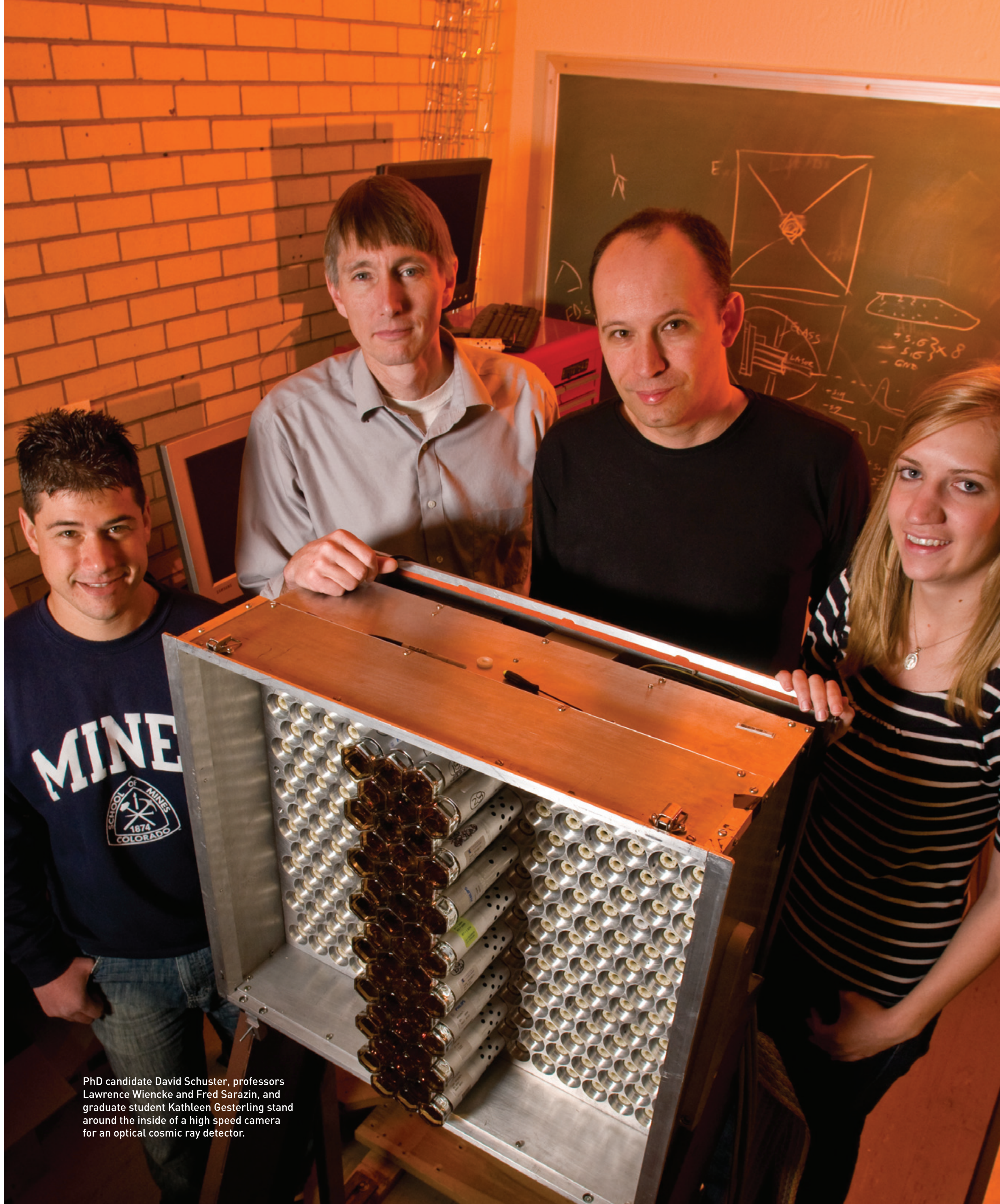
So the collaboration is planning a companion instrument seven times larger than the one in Argentina, to be built in southeastern Colorado in Prowers County. If the funding comes through from U.S. and international agencies, the new Pierre Auger Northern Observatory will bring significant responsibilities and opportunities for Mines.

A research and development project over the next year will characterize the area's atmospheric clarity and deploy a small array of surface detectors. So far, scientists from 10 institutions and four nations are involved in this program. Mines students are expected to contribute to the efforts in Golden as well as on-site.

If funded, construction of the full array is slated to begin by 2012 and would continue for five years, creating new jobs.

That's something the area could use — according to the U.S. Census, Prowers County has a 20 percent poverty rate. The region stands to benefit economically and culturally from the project just as Malargüe, Argentina, did as a result of the southern observatory.

Altogether, the northern observatory is expected to cost about $120 million dollars. Six buildings will be constructed to house optical instruments and 4,400 solar-powered detectors will be fabricated and deployed in a grid-pattern covering 8,000



PhD candidate David Schuster, professors Lawrence Wiencke and Fred Sarazin, and graduate student Kathleen Gesterling stand around the inside of a high speed camera for an optical cosmic ray detector.

square miles and spanning four or more Colorado counties. After construction the observatory will hire staff to maintain the instruments, support data collection operations and assist visiting scientists.

"The establishment of such an observatory in Colorado will be a fantastic opportunity to showcase science in Colorado and encourage more students into science. Mines will also directly benefit from being part of such a large international collaboration doing research right here in Colorado," Sarazin said.

The Pierre Auger Southern Observatory, named after the French scientist Pierre Auger, who invented the first technique to measure UHECRs, covers an area the size of Rhode Island in a remote area of Argentina in the Pampas grassland region. The collaboration of about 350 scientists and engineers from 17 countries built the detector to measure air showers induced by the interaction of UHECRs with the upper atmosphere to learn more about the nature of these elusive particles.

"The cosmic-ray showers are actually made of billions of particles traveling nearly at the speed of light towards the ground. The higher the energy of the incident particle, the larger the size of the shower," said Sarazin.

The observatory relies on two ways to measure the properties of the air showers. On the ground, surface detectors are placed over a large area to detect a tiny fraction of these secondary particles. By measuring the imprint of the shower over several square miles, scientists can determine empirically the energy of the primary particle.

In the second method, four optical detectors operate on clear, moonless nights to record faint traces of fluorescent light from the showers as they race through the atmosphere before reaching the surface detectors. The hybrid measurements provide a more precise description of the shower's energy and evolution.

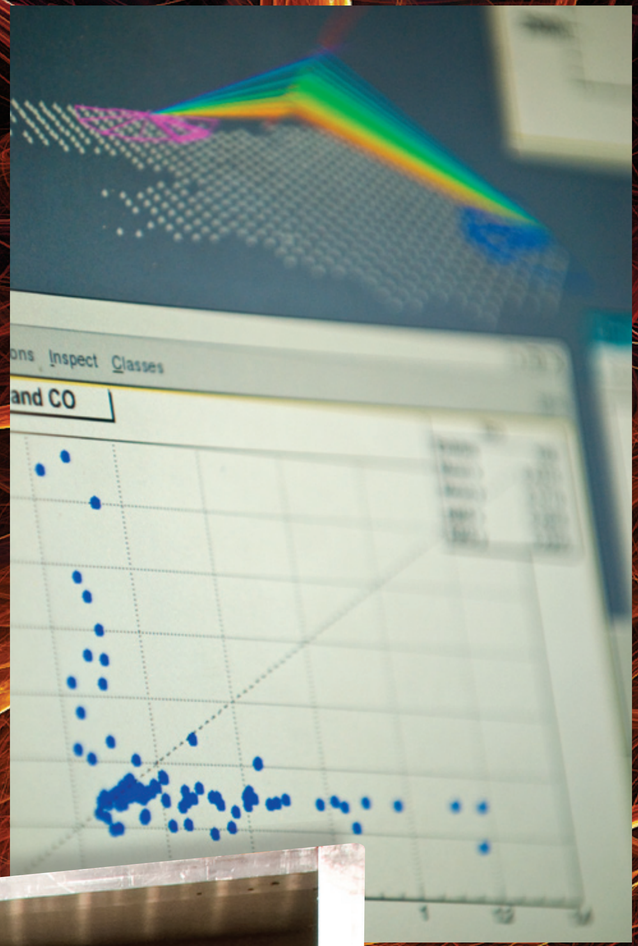
"The goals are to discover the astrophysical origins of these extreme particles and to learn more about the interactions of subatomic particles with macroscopic energies," Wiencke said, noting that sometimes decades later applications are discovered for experiments that the original researchers couldn't have imagined.

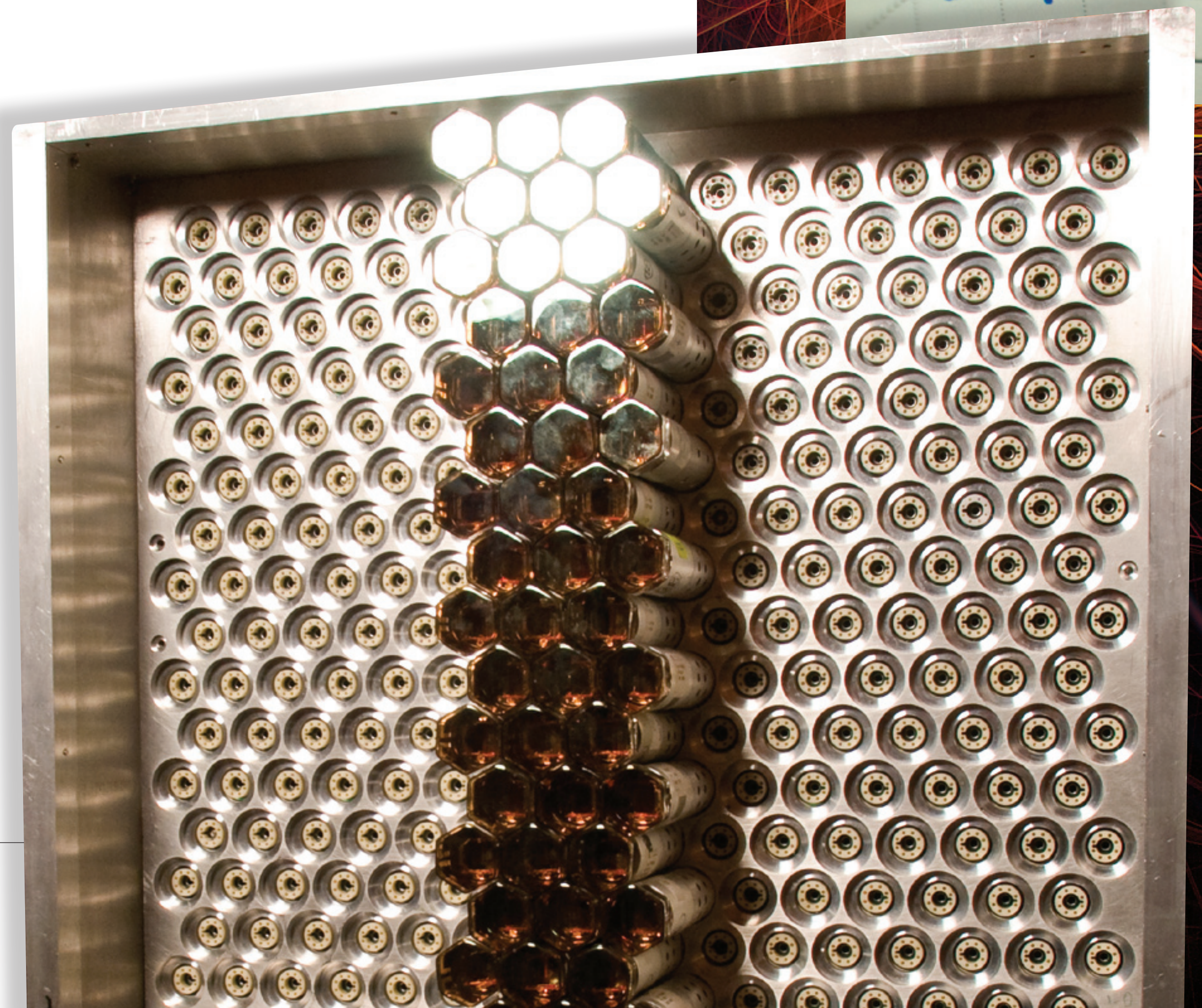
Mines professor Manoja Weiss and staff member Orlen Wolf also are collaborating on the observatory research, which is funded in the U.S. primarily by the National Science Foundation and the Department of Energy. At Mines, the Colorado Energy Research Institute, the Physics Department and the Office of the Vice President for Research and Technology Transfer provided research seed grants. Recently Xcel Energy provided additional funds to support research and development.

Mines students are finding the observatory provides a vehicle for a variety of promising research projects. For instance, the Auger group at Mines looks for signatures of exotic objects — micrometeorites, quarkballs, micro black holes to name a few — in the cosmic-ray showers.

The signatures are theses subjects for PhD candidate David Schuster and master's candidate Kathleen Gesterling, both of whom have presented their work at an Auger collaboration meeting.

Mines undergraduates are getting in on the action, too, doing their senior design projects with the group. A robotic laser calibration system built by two physics majors is in operation at the observatory. Teams also are working on a portable optical cosmic-ray detector, measuring the accuracy of GPS clocks that coordinate the observatory's detector units, and have built a small detector that undergraduates in the physics advanced laboratory class are using to measure the lifetime of low energy cosmic-ray muons.





The camera will be installed at the focus of a large mirror. The hexagonal structures in the camera are photomultiplier tubes that record 20 million images per second of the ultraviolet light generated by a high energy cosmic-ray collision or by a calibration laser pulse passing through the atmosphere.

Discovering ways to make algal fuel more affordable

BIOFUEL **POTENTIAL**

Matthew Posewitz, an assistant professor in the Department of Chemistry and Geochemistry, is examining how microorganisms are able to convert sunlight and water into fuel. By studying microorganisms such as algae, researchers hope to find viable ways to produce biodiesel.

"We study the ability of algae to use photosynthesis to produce a variety of renewable energy carriers including hydrogen, alcohols and diesel fuel surrogates," Posewitz said.

Algae lack leaves, roots and organs and the vascular structure found in plants. Algal fuels can be produced using wastewater or seawater and are biodegradable. U.S. Department of Energy studies found algal fuel to be too expensive in the 1990s, but with increasing petroleum costs and decreasing algae production costs, it's now a hot topic in the biofuel industry.

Australian researchers recently concluded that with additional optimization, some saltwater algae might be able to produce biodiesel for less than what it costs to produce petroleum diesel. Unlike corn, algae can be grown year-round in warm climates on relatively small amounts of land. In its April 2009 issue, *Biodiesel Magazine* quoted Houston-based biofuels analyst Will Thurmond, predicting U.S. biodiesel production from commercial-scale algae as early as 2012. Thurmond believes it will be a mainstream commodity by 2020.

Although Posewitz said making commercially competitive hydrocarbons from algae is a matter of tweaking and optimizing what researchers already are doing, and overall he's optimistic about the potential of biofuels, he cautions we still have a long way to go to make algal fuel cost-competitive.

"The capacity (for biofuels) is definitely there. It's a feasible thing that we could replace substantial amounts of our fuel portfolio, potentially all of it," Posewitz said.

Posewitz and his research team have been working on biofuel production for more than a decade, and now he collaborates with Mines chemistry and geochemistry faculty Kim Williams, Kent Voorhees and Ryan Richards; environmental science and engineering professor John Spear; and physics professor Jeff Squier.

"Our research is focused at the moment on making fundamental advances in our understanding of the metabolic underpinnings of biofuel production. As new discoveries are leveraged in biofuels applications, all of society stands to benefit," Posewitz said.

Posewitz also is a visiting research scientist at the National Renewable Energy Laboratory (NREL). NREL researchers work with Posewitz and his team, which collaborates with scientists throughout the U.S. and abroad. They have extensive collaborations with researchers at the University of Colorado, Stanford University, Princeton University, Westminster College, the University of Hawaii and Montana State University.

"The expertise that these groups bring to the table has dramatically facilitated our progress on a number of projects. By engaging and working with the top laboratories in the country, we are able to move our projects from the conceptual stages to having significant data in our hands much more rapidly. This area has so much interest at the moment that it is really important to exchange ideas with others and address the fundamental bottlenecks in this field, which include optimizing photosynthetic conversion efficiencies, controlling metabolic flux into the desired pathways and extracting the targeted biomolecules from the algae," Posewitz said.

Mines undergraduate and graduate students also are participating in the research and gaining valuable experience.

Funding for the research comes through a variety of sources including ConocoPhillips, the U.S. Department of Energy, the Air Force Office of Scientific Research and the Colorado Center for Biofuels and Biorefining. Over the last five years, Posewitz has received more than $1.5 million in research funding.

Posewitz has published more than 20 papers, including two that were acknowledged by the Faculty of 1,000 (a web site for scientists providing rankings and commentary on current research) as being among the highest impact papers in their respective fields.

Professor Matthew Posewitz

Photos: Kirsten Boyer

André Revil in his lab

Diagnostics for a wide range of applications, including the growing field of geothermal energy

EARTH **DOCTOR**

His geophysical research could be compared to medical imaging — but André Revil, an associate professor of geophysics at Mines, said it differs in a major way.

"I don't know in advance the architecture of the system I am going to image. Maybe I am a doctor of the Earth, at least in terms of establishing a diagnostic of problems," he said.

"I think that if we want to live in harmony with our environment, we need to understand it and geophysics offers a wide range of minimally intrusive methods to diagnose the Earth," Revil said.

Revil uses a multidisciplinary approach to his research on the transport and mechanical properties of porous media, such as rocks and soils. Some of his diagnoses help in planning for occurrences of contaminant plumes and volcanic disturbances.

"I have been working on contaminant plumes associated with landfills using geoelectrical methods to image the distribution of the contaminant in a shallow aquifer. These results were used to plan an efficient remediation strategy for this contaminant plume," he said. "The data we collected were also intriguing because the plume was behaving like a giant geobattery in which biofilms of bacteria were potentially playing a major role."

This discovery led Revil to investigate the problem in more detail. He's preparing a manuscript for the *Journal of Geophysical Research – Biogeosciences* regarding the role of biofilms in the generation of electrical signals in this type of contaminant plume.

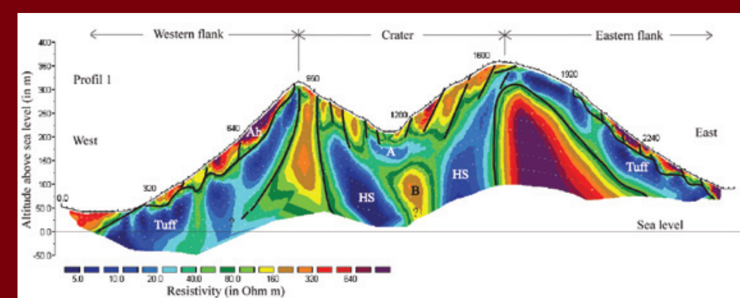
At Stromboli and Vulcano in the Eolian Islands north of Sicily, Revil and his colleague Anthony Finizola, from the University of La Réunion in France, have obtained the first images of the volcanoes' architecture. These images help the Italian authorities prepare better geohazard maps for these volcanoes and to plan the potential effects of flank collapses.

Revil is interested in the relationship between porous media and geophysical methods — especially active and passive electromagnetic methods like electrical resistivity, induced polarization and self-potential.

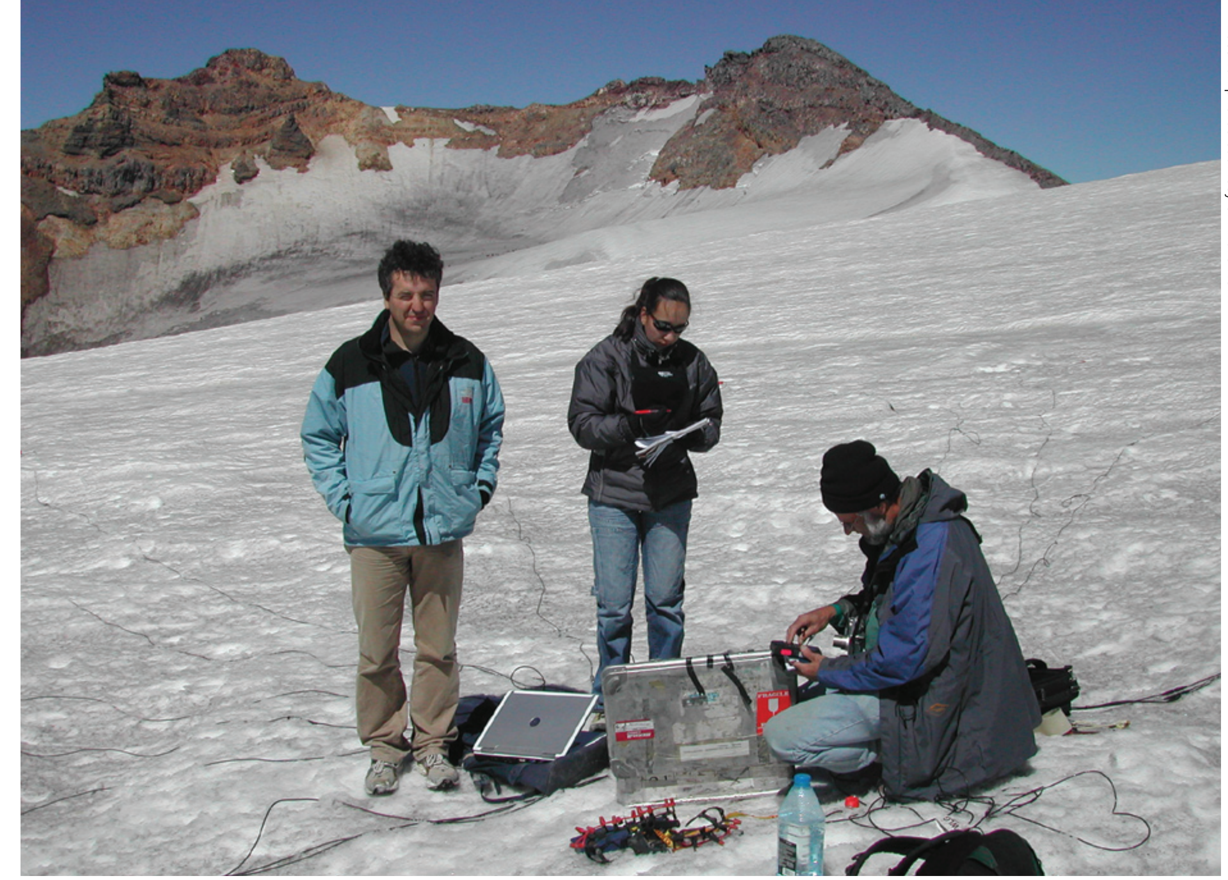
These methods can be used to image the ground and dynamic processes occurring in the ground like water flow or the transport of contaminants.

Lake at the summit of Mount Ruapehu, New Zealand

Revil on the glacier at the summit of Mount Ruapehu, New Zealand



This graphic is a tomographic image of a cross-section of the vulcano edifice on the island of Vulcano, Aeolian Islands, north of Sicily in Italy. Revil and his team performed 3D imaging of the volcano's interior and are preparing a paper for *Nature* based on the research.



Location photos courtesy of André Revil

Studying the hydrothermal system under the volcano, Mount Ruapehu, New Zealand. Left to right: Revil, Aurélie Legaz and Tony Hurst.

In this research, Revil is working at vastly different scales from molecular to geological structures — volcanic edifices and faults, for example — and is equally at home testing core samples in the lab or working in the field monitoring active volcanoes. His methodology includes theory, forward numerical modeling and inverse modeling. He's also been known to mix interfacial chemistry, transport properties of porous media, mechanics of porous media and geophysical methods in unique ways.

The spectrum of applications for this research is wide, including monitoring active volcanoes and fault activity, non-intrusive imaging of groundwater flow and contaminant plumes, locating cavities and sinkholes for geohazard mapping, and evaluating properties of clays for long-term storage of nuclear wastes.

Lately he's focused on a promising new technology for imaging oil and gas reservoirs called the seismoelectric method.

In the oil industry, the queen of all the geophysical methods is the seismic method. A mechanical source is used to send waves into the Earth and the seismic waves reflected are analyzed to provide an image of the ground. The seismoelectric method works similarly, but researchers look for the electromagnetic conversion of the seismic waves.

This method has the potential to combine the high resolution of the seismic method with the sensitivity of the electrical method to the material properties of rocks and especially to fluid contents. This approach could be used to detect oil and gas reservoirs, to non-intrusively image the water table and to detect the shape of non-aqueous fluid phases in the ground — like those associated with oil spills. He hopes to obtain oil industry funding to pursue this exciting new research area.

Revil said research conducted in a new Mines lab he is developing could contribute to the growing field of geothermal energy — especially in Colorado. He's working alongside Mines geophysics professor Mike Batzle and Boise State University professor Kasper van Wijk near Mount Princeton Hot Springs in the Arkansas Valley. The goal of their research is to image the pattern of ground water flow in the area and to see how many megawatts of electricity could be produced by preserving the environment and the geothermal resource.

"Such a work is important to alleviate our dependence on fossil fuel as tens of such potential hot spots for geothermal resources exist in Colorado. However, you want to be sure that if you tap into these reserves, they could be used for the long term, which requires planning effectively with this type of study. Here too, geophysics play a critical role in understanding how water flows in the ground," Revil said.

He also is working on a unifying theory of transport properties in porous media that will have applications in geophysical methods and the fusion of the geophysical information and measurements taken on-site.

Currently Revil collaborates with more than 15 universities and research labs worldwide, including universities in France, Italy and Germany. His fieldwork has taken him to Nepal to look for the emission of radon and carbon dioxide associated with tectonic faults (useful in predicting earthquakes) and to New Zealand where he studies geothermal fields.

Fifteen Mines students are active participants in Revil's research.

His research funding comes from the Department of Energy and National Science Foundation in the U.S., from the French National Research Agency and ANDRA, the French agency for the storage of nuclear waste.

Finding technological solutions for environmental and economic problems

Math for MINING

Graduate student Larry Clark, Mining Professor Kadri Dagdelen and graduate student Chotipong Somrit

The mining industry today faces environmental, health and safety, and economic challenges requiring sophisticated solutions. Kadri Dagdelen, professor and interim head of the Mining Engineering Department at Mines, helps mining companies plan and operate mining projects more efficiently by building large-scale mathematical models of mines and process plants that contain tens of millions of variables and hundreds of thousands of constraints.

"I have spent the last 30 years both in academia and in industry developing mathematical models and solution methodologies to be used as an effective tool by mining engineers in the field to increase profitability and to reduce the environmental impact of mining projects," Dagdelen said.

Since neither mining companies nor software companies have the expertise and time for the research and development of these technologies, they have found it more profitable to team up with experts like Dagdelen by funding his research projects at Mines.

For example, since the mid-1990s, Dagdelen has assisted Newmont Mining Corp. in the development and implementation of mixed integer-linear programming models for their Nevada gold mining operations — saving the company tens of millions of dollars.

The models Dagdelen develops help improve the net present value of projects by finding the most appropriate sequence and processing options for ores coming from open pit and underground mines, while minimizing the environmental impact of extraction and the mine closure.

"Our research benefits large mining companies by reducing capital and operating costs of large multi-mine, multi-process projects through more efficient mining planning techniques," Dagdelen said, noting his PhD students are involved in the research projects.

In addition to Newmont, industrial research partners include Placer Dome, Phelps Dodge, Kinross and recently Freeport McMoran Inc., Barrick Resources and other mining companies. The research takes place in the U.S.; Canada; Ghana and Tanzania, Africa; Peru and Chile, South America; and Turkey, and is funded mostly by the mining industry.

"The environmental health and safety, and economic challenges facing the future of the mining industry will be more complex and intricate. The creative and technically advanced environment in the Mining Engineering Department at Mines is already addressing many of these issues by pushing technological advancements and providing innovative approaches to solve these problems," Dagdelen said.

Research is carried out on a continuing basis at Mines' Edgar Experimental Mine in Idaho Springs, Colo. Academic, government and industry groups participate in cooperative studies, including tunnel detection, blasting, rock mechanics, development of new mining equipment and methods, and specialized mine rescue training. Dr. Mark Kuchta is the Edgar Mine director.

NEW FACULTY PROFILES

FINDING NEW DIAGNOSTIC TOOLS FOR BLEEDING DISORDERS

Keith Neeves

Blood clots, in the form of heart attacks and stroke, are the most common cause of death in the U.S. Keith Neeves, an assistant professor of chemical engineering at Mines, is studying how blood clots form and dissolve in hopes of devising new ways to recognize and treat bleeding disorders.

"Our work is considered translational medicine, which means we are trying to translate basic research findings into clinical practice. In our case this means new diagnostic tools for bleeding disorders. It's exciting to be working on a problem that has such immediate clinical relevance," Neeves said.

His research uses micro- and nanotechnology techniques to make devices that simulate how clots form.

Because Neeves comes at these problems as an engineer, his methods differ from those found in a standard blood biology lab. For example, in studying clot formations, most diagnostics are done under static or no flow conditions — but Neeves said it makes sense to study blood under flow, which is a more natural state.

"My training in fluid dynamics and molecular transport gives me a different perspective on blood clots than someone trained as a molecular biologist," Neeves explained.

He was educated in chemical engineering at the University of Colorado-Boulder and earned his PhD in chemical and biomolecular engineering at Cornell University. Before joining Mines, Neeves was a postdoctoral fellow at the Institute of Medicine and Engineering at the University of Pennsylvania. There he was introduced to the subject of blood biology and had the opportunity to work with molecular biologists and clinicians tackling vexing problems that hematologists come across with patients.

Neeves and his wife are Colorado natives, so he welcomed the chance to return to his home state and to contribute to the burgeoning bioengineering program at Mines. He said he appreciated Mines' dedication to teaching because he'd seen that commitment to education is often lacking at larger research institutions.

"People don't think biology when they think Mines, but there are some fantastic faculty across campus who work at the interface between biology and engineering," Neeves said.

Dave Marr in chemical engineering and Jeff Squier in physics also are working on the research, which is conducted in collaboration with the Mountain States Regional Hemophilia and Thrombosis Center at The Children's Hospital in Denver. Neeves and the other researchers are working out new methods for diagnosing bleeding disorders, primarily focusing on von Willebrand disease, the most common and hardest to diagnose bleeding disorder.

"People with von Willebrand disease form poor clots because their platelets can't stick to an injured vessel wall very well," Neeves said.

In another partnership, Neeves works with researchers at the Center for Nanophase Materials Sciences at Oak Ridge National Lab to fabricate vascular and tissue mimicking devices. These devices allow researchers to deterministically study how molecules move in the very small spaces between adjacent cells. This is an important phenomenon to understand when devising strategies to break up a blood clot.

"There is a lot of focus on driving down the cost of health care and pharmaceutical research and development. I think my research lends itself to developing the new medical infrastructure, which will depend on cheaper, faster and more sensitive diagnostic tools. Many of the current blood diagnostics are expensive and incapable of making a good diagnosis except in the most extreme cases. Furthermore, the same tools we use for diagnostics can be applied to screening of pharmaceuticals," Neeves said.

His work has earned him the National Institutes of Health's Ruth L. Kirschstein National Research Service Award and a post-doctoral fellowship from the American Heart Association (AHA). Federal support comes from the National Institutes of Health and from AHA and other non-profit foundations.

Neeves said undergraduate students have been instrumental in establishing his lab. Students in bioengineering and life sciences programs can take courses preparing them for careers in biofuels, pharmaceuticals and medicine.

Bioengineering is the fastest growing discipline in engineering, Neeves said.

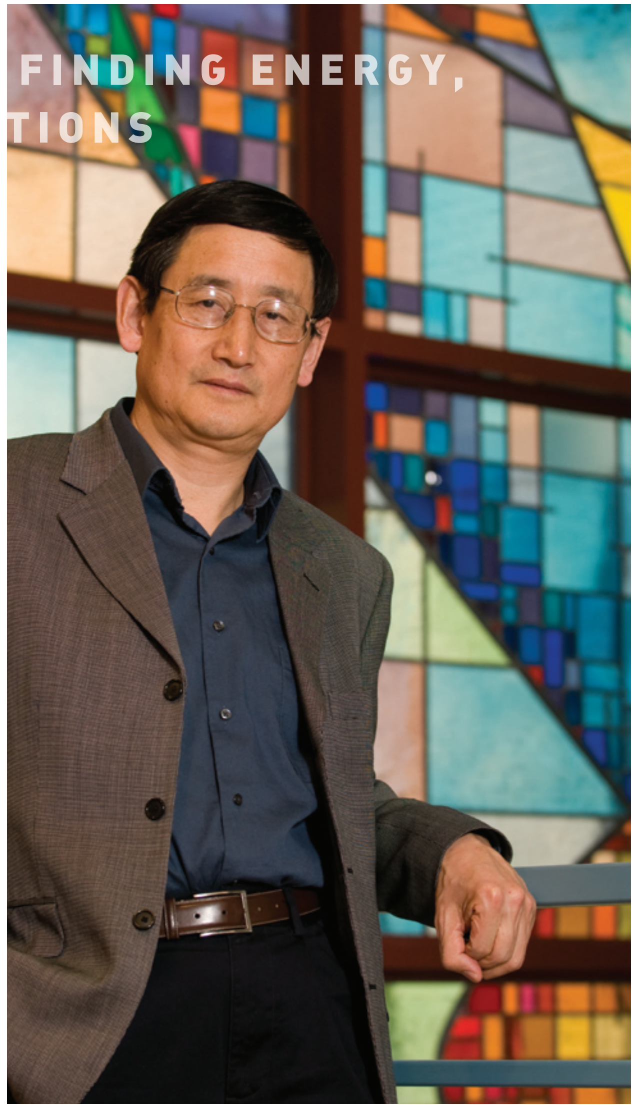
When he isn't teaching or conducting research, Neeves enjoys reading, running and traveling.

He reads the Sunday *New York Times* in its entirety, along with periodicals that publish new fiction such as *Harper's* and the *New Yorker*, and 15 to 20 books a year. Currently, he's reading *2666*, an 898-page novel by the late Chilean-Mexican author Roberto Bolaño.

Neeves runs in road races from 10Ks to marathons, a hobby that began after several concussions and separated shoulders cut his rugby career short. He's training for the June 14 Rocky Mountain Half Marathon, a 13.1 mile run through Denver.

In the past few years he's logged trips to Guatemala, Ecuador, Spain, the Czech Republic, Ireland, Morocco, Egypt, Israel, Jordan, India, Nepal, Tibet, Vietnam, Laos and Thailand.

COLLABORATION IS KEY TO FINDING ENERGY, ENVIRONMENTAL SOLUTIONS



Yu-Shu Wu

Petroleum Engineering Professor Yu-Shu Wu has an office in Alderson Hall on the Mines campus. It's one of many.

He's working with the Earth Sciences Division of the Lawrence Berkeley National Laboratory in California; with the Research Institute of Petroleum Exploration and Development, Peking University's College of Engineering, and the Daqing Petroleum Institute in China; and with HydroGeoLogic Inc. in Virginia.

It's part of his belief that collaboration both within and outside Mines is crucial to making major headway in developing solutions for the world's energy and environmental future. He said involving multidisciplinary fields is a more efficient way to go.

"In most cases, collaboration is the key to generate new research ideas, combine expertise, share labs and computing facilities, and conduct significant scale investigation from lab to field," Wu said.

He earned his BS and an MS in petroleum engineering in China and an MS and PhD in reservoir engineering from the University of California at Berkeley.

Wu works in quantitative evaluation of fluid flow, chemical transport and heat transfer in porous media. The research has applications for petroleum reservoirs, nuclear waste disposal and in sequestering carbon dioxide.

His research involves:

- Developing effective production and recovery technologies of petroleum and gas in low-permeability reservoirs
- Investigating effective carbon dioxide flooding/storage methodologies by injecting large amounts of carbon dioxide into mature oil and gas reservoirs for both enhanced oil and gas recovery and long-term carbon dioxide geosequestration
- Evaluating safe disposal of nuclear waste in subsurface formations

"Considering oil and gas reserves from low-permeability, tight sand and shale formations contribute significantly to oil and gas reserves — and they have the potential to provide us with sufficient energy for decades to come — these areas are critical to address both issues of increasing energy supply and reducing carbon dioxide atmospheric release of climatic concerns," Wu explained.

Before coming to Mines, Wu worked as a staff geological scientist for 14 years at the Lawrence Berkeley National Laboratory. One of his major projects there was leading a multidisciplinary team in quantitative investigations for the Yucca Mountain nuclear waste storage project, which was one of the world's largest research efforts into reservoir characterization.

One of his early jobs was as a petroleum engineer in the oil fields of China. Wu said he came to Mines because of the school's excellent reputation in the areas of geosciences, energy and water resources, and environment.

Wu's Mines collaborators include Hossein Kazemi, Erdal Ozkan, Jennifer Miskimins, Xiaolong Yin and Ramona Graves in petroleum engineering; Dendy Sloan and Carolyn Koh in chemical engineering; and Ning Lu in engineering.

Wu said he finds the potential to discover a better solution for our energy and environmental future a particularly exciting aspect of his research. That prospect has become even more relevant in recent years with the rapid increase of the world's energy demand and growing environmental concerns about climate change.

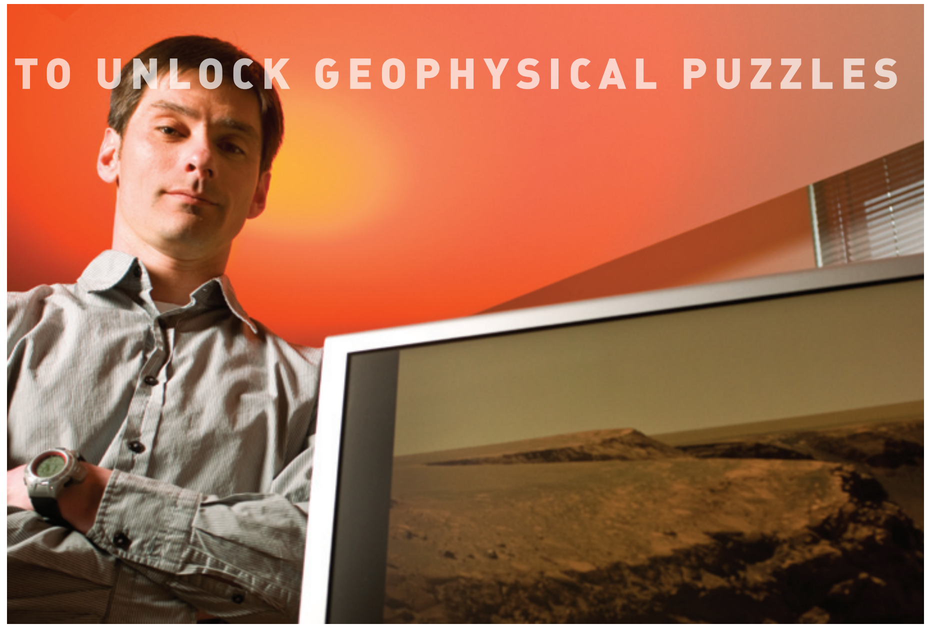
Although carbon dioxide flooding has been used since the 1970s by the petroleum industry to increase oil recoveries, Wu's research into underground carbon dioxide storage, coupled with carbon dioxide-enhanced oil recovery for reducing costs, is new. Its goal of generating fundamental understandings of carbon dioxide flow and phase behavior in long-term storage reservoirs is significant.

Throughout his career, Wu is credited with authoring and co-authoring more than 200 scientific papers and technical reports, including 70 peer-reviewed journal articles. He served as associate editor for *Water Resources Research Journal*, currently is review chair for *SPE Journal*, and has served on journal editorial boards and reviewed research proposals for the National Science Foundation and Department of Energy. He was named a Fellow of Geological Society of America for his work in nuclear waste disposal.

Looking to the future Wu said, "How and when we determine carbon dioxide geosequestration is the solution to carbon dioxide atmospheric release." And considering the past he said, "I have fortunately had opportunities to work with and learn from some of the best geo-scientists, reservoir engineers and modelers in the world."

In his spare time, Wu said he enjoys travel and outdoor activities, such as jogging and camping, and especially skiing — even though he said he isn't very good at it.

LOOKING TO MARS TO UNLOCK GEOPHYSICAL PUZZLES



Jeff Andrews-Hanna

For many kids, a backyard telescope opens a world of wonder. For Jeff Andrews-Hanna, a look at Mars opened a career path.

He took his first planetary science class as a sophomore at Cornell University and remembers being "hooked" when his professor spread out a map of Mars filled with landscapes he'd never imagined. Although his interests span the solar system, he's still captivated by Mars.

"The goal of my research is to try to understand how and why the planets are different. Some of my main interests are in the areas of tectonics, geodynamics, hydrology and climate evolution of Mars, and the crustal structure of both Mars and the moon," he said.

As a planetary scientist, Andrews-Hanna focuses on the geophysics of the terrestrial planets using a combination of data analysis and computer modeling to investigate the evolution of the surfaces and interiors of the planets.

His fascination with the Red Planet, so-dubbed because of the prevalence of iron oxide (rust) on its surface, is twofold. First, he's eager to explore different worlds and solve puzzles early astronomers could only dream about. Second, he believes understanding the staggering climate changes that transformed Mars from a warm, wet planet to a cold, arid desert could hold answers for Earth's climate change.

"We may learn a lesson from Mars, which preserves on its surface the record of the most dramatic climate change in the solar system," he said, explaining that sometime around four billion years ago, Mars underwent a transition from being an Earth-like planet to one with an atmosphere less than one percent as thick as the Earth's.

"We are a long way from understanding the cause of this climate change, but it stands as a warning that our climate on Earth is not something that should be taken for granted," he added.

Mars isn't the same as the Earth by any means, but it holds some familiar features: volcanoes, faults, canyons and river valleys. Earthquakes there may have triggered floods, and volcanic eruptions deformed the entire planet and created a global set of faults. Enormous volumes of water on the scale of a thousand Mississippi Rivers simply erupted from the ground.

Its mysteries are many and Andrews-Hanna is acutely aware he lives in the first century capable of unraveling them.

Through his vigilant research and willingness to challenge established ideas, he worked to dispute a long-held belief about Mars. The topography of Mars is dominated by a hemispheric dichotomy between the southern highlands and northern lowlands. The old view held this came about from internal processes, but Andrews-Hanna found support for a contrary hypothesis in which an impact from a giant asteroid caused the split. It's still up for debate, but he said the research opened up a new understanding of the history of Mars.

Andrews-Hanna joined the Mines Geophysics Department as an assistant professor last fall after completing his post-doctorate work at MIT. He earned a PhD from Washington University in St. Louis and a bachelor's from Cornell University. Mines' reputation in earth sciences and its cutting-edge research attracted him to the school, where now from his computer in Golden he vicariously visits Mars, the moon and other planets.

Andrews-Hanna follows a long line of researchers in his endeavors, and he currently works with scientists at a variety of schools and institutions. He and colleagues at MIT are studying density variations in Martian polar caps. Washington University and California Institute of Technology researchers are working with him to study the hydrologic and climatic evolution of early Mars using a combination of modeling and remote sensing. He and Jet Propulsion Laboratory scientists are studying the hydrology of Saturn's moon, Titan. In another project, he's collaborating with Boulder's Southwest Research Institute.

Grants from NASA fund these projects, which are unique from other research in part because of Andrews-Hanna's inclination toward combining multiple approaches and perspectives.

"Some of the most interesting problems deal with the intersection of different types of processes," he said.

The challenge for him is to figure out how to approach a problem. He said creativity is important, but it's also essential to be well-grounded in theory.

"In my mind, planetary science is at a stage right now that is analogous to the early days of geology — when plate tectonics was considered to be a wild theory and we found more questions than answers everywhere we looked," he said. "But unlike the early days of geology, in planetary science today we can tackle these problems with the aid of a tremendous amount of new data, state-of-the-art computational tools, and the wisdom gleaned from a long history of studying the Earth."

His works have been published in *Nature*, *Science* and other journals, and featured in *Science News*, *Discover Magazine* and *National Geographic* and also will be featured in an upcoming Discovery Channel documentary. As a graduate student, Andrews-Hanna garnered the Dwornik award for best presentation at the Lunar and Planetary Science Conference.

Although his thoughts are often millions of miles away, Andrews-Hanna has some decidedly earthbound interests, including hiking, backpacking, running, cycling and both cross-country and telemark skiing. He's taken extended multi-week wilderness trips to Alaska, the Northwest Territories in northern Canada, and East Africa.

TEACHING COMPUTER SCIENCE BY UNDERSTANDING HOW STUDENTS LEARN

Irene Polycarpou

When Irene Polycarpou was an undergraduate at Florida International University (FIU), she volunteered to tutor students in the School of Computing and Information Sciences and ultimately realized what would become her life's work.

She learned what worked for one student didn't necessarily work for the next, even if they were struggling to understand the same concepts. Polycarpou soon realized two things: students have diverse learning styles and she wanted to contribute to the advancement of computer science education.

Today her research focuses on computer science education — more precisely, at the intersection of instructional software and students' cognition and learning styles. Despite high dropout rates for computer science students in recent years, industry demand for computer scientists continues to increase.

"To lower the computer science dropout rates, it is essential to monitor students' progress, identify the 'most challenging' courses, enhance the current curriculum and accommodate the students' needs to the best possible extent," she said.

Polycarpou said one approach for improving computer science education involves embracing technology, such as instructional software, which is usually visual and interactive in nature. By effectively utilizing educational technologies, educators can accommodate students' diverse learning styles and help them overcome their difficulties in understanding and applying computer science concepts.

Currently, there are many educational software programs available for teaching and learning computer science concepts, especially in the areas of algorithm design, programming and automata theory. Polycarpou works closely with students to identify problem areas and to find new teaching approaches.

"It is very rewarding to see the outcomes of your research being applied and hear students' stories about how their understanding of certain concepts has been improved as a result of your research," she said.

Polycarpou earned her BS, MS and PhD from FIU before joining Mines as an assistant professor of mathematical and computer sciences in 2008. One incentive for her move to Colorado was the K-12 outreach program through Mines' Center for Assessment: Science, Technology, Engineering and Mathematics (CA-STEM) where her research can be applied. Now she's working on a CA-STEM project involving K-12 students and teachers in Colorado to improve science, mathematics and engineering instruction.

The project is a collaborative effort between CA-STEM, Mines' Renewable Energy Materials Research Science and Engineering Center, the National Renewable Energy Laboratory and Colorado school districts. It focuses on developing teaching materials for mathematics, engineering and science concepts in relation to renewable energy. Polycarpou plans to pursue more energy-related projects because such topics motivate students.

Her research, which is grant funded, takes place in Colorado and Florida. Faculty involved with her research include Mines mathematics and computer science professors Barbara Moskal and Cyndi Rader, and engineering professor Cathy Skokan, as well as FIU computer science professor Ana Pasztor.

In a prior project, Polycarpou collaborated with FIU researchers to develop educational software for teaching and learning "proofs by induction" for computer science. Proofs by induction are at the core of many computer science areas such as theory of computation, algorithm correctness, program verification and algorithm efficiency.

Even though computer science students come across proofs by induction in many courses of their curricula, they have difficulties understanding and performing such proofs, even after repeated instruction. Polycarpou worked closely with students and conducted numerous studies to identify the exact sources of their difficulties with proofs by induction. She then combined her results with the relevant literature on students' learning styles and cognition to design and develop a multimodal and interactive electronic book for teaching and learning proofs by induction for computer science. She designed her e-book for use as a stand-alone learning tool for students to learn induction as well as a teaching tool for instructors.

While at FIU, Polycarpou received the Outstanding PhD graduate award.

When Polycarpou isn't devising better ways to teach computer science, she's often traveling to new places, experiencing different lifestyles and cultures and sampling local cuisines. Her hobbies include cooking, hiking, swimming and skydiving, which she first tried as a freshman in Miami.

Research CENTERS

From top, professors Michael Kaufman and John Speer work with PhD candidate Ryan Regier on characterizing the microstructure of a fire-resistant steel on a high resolution field emission scanning electron microscope, with energy dispersive x-ray spectroscopy, electron backscatter diffraction and nanolithography capability.

Forging Ahead in Steel

One of the technologies that most changed modern society was the refining of iron. Steel — an alloy of iron, carbon and other elements — is a major component of automobiles, bridges, skyscrapers, tools, ships and many other modern products society has come to rely on. And for all the changes in the world, steel remains a key material for many critical engineering applications.

The Advanced Steel Processing and Products Research Center (ASPPRC) at Mines was established in 1984. Its mission then, and today, is to conduct research to benefit steel users and producers, to develop national and international forums, to educate graduate students in theoretical and practical research applications, and to provide a stimulating academic environment for undergraduate education.

Led by Director David Matlock, the center's research focuses on three areas:

- Bar and forging steels that are used in gears, springs and shafts
- Sheet and coated steels that are used in automobile bodies and appliances
- Plate and hot rolled steels that are used in pipelines, heavy equipment and offshore structures

Matlock is joined in the center by Metallurgical and Materials Engineering Department members John Speer, Chester Van Tyne, Kip Findley, Professor Emeritus George Krauss, Steven Thompson; post-doctoral research associates Emmanuel DeMoor and Seok-Jae Lee and office manager Elaine Sutton.

Because steel remains a critical material in all aspects of our society, Matlock said new steels with better properties — higher strength, better corrosion resistance and improved appearance — are required to remain competitive and respond to the changing needs of the industry.

"For example, all automobiles depend on steel as the material of choice for construction as steel is the only material that provides the necessary properties at an economical price. Center research has and continues to contribute to these advancements," Matlock said.

And it isn't just the auto industry that needs newer and better steel. Materials for new bridges, building construction and infrastructure redevelopment require new steels with improved properties produced more efficiently.

Gas and oil pipelines will require stronger, tougher steels to allow larger diameter pipelines to be produced more economically with improved safety. The development of new offshore, deepwater oil and gas reserves also demands new materials with significantly enhanced properties. Since steel remains the primary material for all of these applications, the center's research is on the forefront of developments.

"These developments will benefit all segments of society. Steel-based manufacturing is an important source of quality employment," said Speer.

A unique aspect of the center's work is that it involves both users and producers of steel working together in a partnership with the university, even when some of those partners are direct competitors. Because they're working for the same goal, to produce improved products at lower cost, they put aside any marketplace rivalries to work together with Mines.

"Nowhere else in the world is there a research program at a university with the same structure and focus as there is here at Colorado School of Mines," Matlock said.

But what happens at Mines doesn't stay at Mines.

"ASPPRC graduates over the past 25 years now populate companies, many in significant managerial roles, that will provide the critical materials and technology to enable future energy developments," said Speer.

Steel advancements are vital to improved fuel economy, reduced carbon dioxide emissions and passenger safety in the auto industry. And steel is a critical component of advanced bridge and building designs and to the world's manufacturing infrastructure.

Infrastructure construction and manufacturing are important components of job creation efforts, where steel maintains a central role.

One example where steel is a critical enabler for the development of new energy sources is in wind energy. Harnessing wind energy depends on high strength, lightweight, economical steel towers to support wind turbines. Each tower transmits wind energy through a series of steel gears and shafts to an electrical generation system. These gearbox components must be designed for low maintenance and long life, characteristics only available with steel components.

Because of steel's ubiquitous nature, it isn't surprising the center's collaborations are worldwide, with ties in Korea, India and Europe, including partnerships with corporate and national laboratories and at other universities around the globe.

Some of its many corporate sponsors include Caterpillar, John Deere, General Motors and Toyota and major steel corporations such as U.S. Steel and the Timken Co. Annual consortium fees paid by industrial participants generate most of the center's funding. The remainder is derived from directly sponsored industry contracts and government grants, including funds from the National Science Foundation.

Along with the development and implementation of new steel products, the center is charged with providing the necessary educated talent to support these industries in the future. Most of the research involves graduate students, but last year a grant from the American Iron and Steel Institute provided funding for ongoing undergraduate research.

The researchers have garnered numerous awards over the years. The Association for Iron and Steel Technology (AIST) will bestow the 2009 Hunt-Kelly Outstanding Paper Award for one of the top three papers published by AIST in the preceding year for *Thermomechanical Processing Effects on the Elevated Temperature Behavior of Niobium Bearing Fire-Resistant Steel* by graduate student Ryan Regier, Speer, Matlock, Amy Bailey (Gerdau Ameristeel) and Steve Jantso (CBMM/Reference Metals), illustrating not only the center's work in advancing steel processing, but also in providing students with meaningful research projects and interactions with external groups.

From left, professor Renaud Bouroullec, graduate students Amy Moss-Russell, Alexandra Fleming and Jeremiah Moody, program manager Charlie Rourke, and graduate student Matt Hoffman join professor David Pyles outside the Chevron Center of Research Excellence on the Colorado School of Mines campus.

Unique Energy Industry Partnership

Chevron is one of the world's largest integrated energy companies, conducting business in more than 100 countries and employing more than 64,000 people. Today Chevron is investing in renewable and advanced technologies, but its roots are steeped in oil and can be traced back to an 1879 oil discovery in California. The company is involved in every aspect of the oil and natural gas industry — exploration, production, manufacturing, marketing and transportation — as well as chemical manufacturing and sales, and geothermal and power generation.

David Pyles, technical research project manager and Mines research professor, leads the Chevron Center of Research Excellence (CoRE); Charlie Rourke is program manager and Renaud Bouroullec is a research assistant professor. The center, part of the Department of Geology and Geological Engineering, promotes four goals: education, training, recruiting and research.

Two researchers and five students are dedicated to the center's research program, which focuses on reducing uncertainties in the interpretation of subsurface geology. The areas of interest include structure and stratigraphy interactions in marine basins and stratigraphic rules. In the former, researchers aim to improve knowledge of the relationship between growing structures on the stratigraphic record, and in the latter, researchers focus on using physical laws and observations to describe relationships between two or more parameters for prediction.

"Our team is collaborating with Chevron researchers to invent new ways for improving our ability to predict stratal relationships in the subsurface. To this end we are studying outcrops from all over the world and relating small-scale features, like bedding and grain size to broader stacking patterns that can be visualized with subsurface data," Pyles said.

The results will help those in the energy industry develop empirical relationships that can be used for prediction. Currently, the industry relies on subsurface seismic data that can't often image strata below the resolution of tens of meters. With the center's research, reservoir management and modeling can be improved.

Chevron meets with center researchers frequently to help define scientifically relevant problems. Through collaborative effort, field-based research projects are devised to address the geological challenges that have direct, short-term impact on Chevron's business practices. The collaboration also involves six other universities.

Research takes place at the Ainsa Basin, southern Pyrenees, Spain; Ross Formation, County Clare, western Ireland; Annot Sandstone, southern France; Point Loma Formation, southern California; Capistrano Formation, southern California; and the Lewis Shale, southern Wyoming.

Pyles said the center's partnership with Chevron is unique. When conventional industry-funded consortiums have several companies invest in solving a common problem, industry partners can be reluctant to share their challenges with the rest of the consortium.

"The uniqueness of our program is that we are funded by one company. As a result, our sponsor is willing to share key geological challenges with us. This allows CoRE to develop field-based research projects that will have short-term impact. The relationship is, therefore, very balanced," Pyles explained.

The center also has a unique approach to outcrop research and is arguably the most measurement-intensive field-based research team in the world. Its findings include empirically relating a channel's cross-sectional asymmetry to the grain size and stratification of the strata that fill it.

The center funds research assistantships and research costs for five graduate students. The center also promotes the education of Chevron's international employees, including two from Indonesia who are currently graduate students at Mines.

The training program focuses on education outreach that mutually benefits Chevron and Mines, including field trips, field schools and short courses at Mines. Over the last year, researchers from Chevron have taught a course in sequence stratigraphy and another in tectonics and sedimentation. Mines students and faculty have attended field schools in Spain, including one on deepwater channelized systems in the Ainsa Basin.

"The unique opportunity for our students is they work on relevant research not only with our research professors but with Chevron researchers as well," said Pyles.

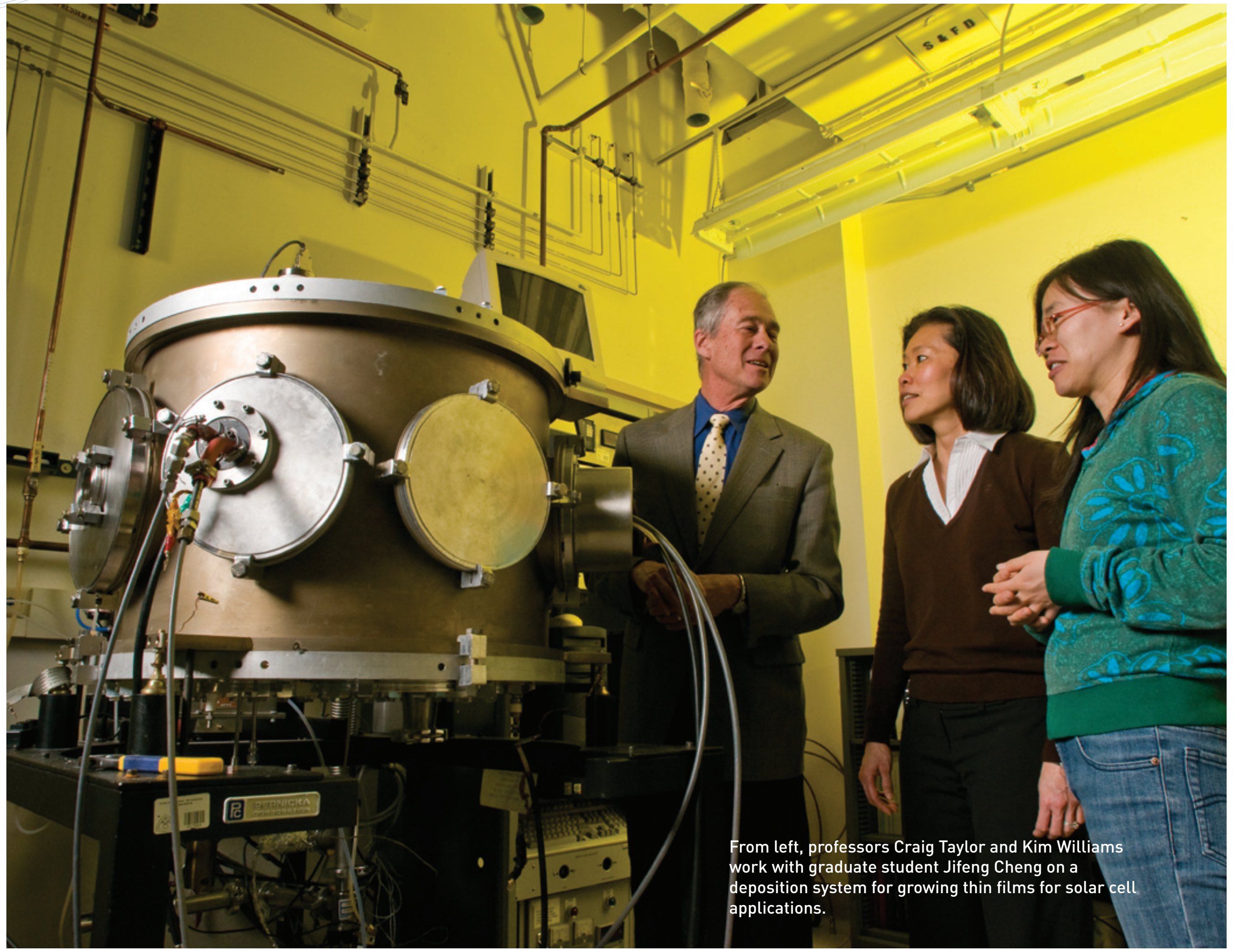
The center has leveraged its position in the geology department and its students have benefited from Chevron recruitments. In the last year, four Mines students have obtained internships at Chevron and three have secured full-time employment with the company.

The center's research has been recognized through numerous awards, such as best paper award in journal articles and best poster and talk awards at conventions. Over the last year, the center's researchers have stacked up a sizeable array of publications: nine journal and book articles (three currently in press), three atlas articles and 15 abstracts in conference proceedings. Three more articles are in review.

Student researchers have garnered a variety of awards as well, including five grants-in-aid awards, two fellowships and two association awards just in the past two years. In addition, Rourke was named one of four Mines representatives for the 2008–09 Academic Management Institute.

From left, Prianto Setiawan, Renaud Bouroullec, Henri Silalahi and David Pyles enjoy a break from fieldwork at the Ainsa Basin in the Spanish Pyrenees.

Below, Jeremiah Moody rappels in his field area, Ainsa, Spain.



From left, professors Craig Taylor and Kim Williams work with graduate student Jifeng Cheng on a deposition system for growing thin films for solar cell applications.

Emerging Energy Materials and Technologies

In September 2008 Mines received a $9.3 million grant from the National Science Foundation (NSF) to establish a center dedicated to investigating emerging renewable energy materials and technologies.

The Renewable Energy Materials Research Science and Engineering Center (REMRSEC) is headed by Physics Professor Craig Taylor. This first NSF-funded center dedicated solely to renewable energy enjoys a strong collaboration with the National Renewable Energy Laboratory (NREL).

The strategic partnership with scientists and engineers at NREL allows for the sharing of students, research associates, equipment and facilities between the two organizations. More than a dozen companies actively involved in alternative energy partner with the center, which also collaborates with the University of New South Wales and Imperial College, London.

"In our first six months of operation we have put in place the organization and infrastructure to make highly significant contributions to materials that are critical to future solar and fuel cell applications and to the storage of hydrogen as a fuel," Taylor said.

REMRSEC is organized around two interdisciplinary research groups and an exploratory research group. The first interdisciplinary group concentrates on harnessing the unique properties of nanostructured materials (those whose dimensions are billionths of a meter) to significantly enhance the performance of photovoltaic devices that directly convert sunlight to electricity. The second group is directed toward advanced composite membranes to enhance the performance of fuel cells and electrolyzers that use fuels such as hydrogen to generate electricity or use electricity to make fuels, such as splitting water into hydrogen and oxygen. The final exploratory group is evaluating the use of open-cage solids called clathrates as potential materials for hydrogen storage.

The goal of Reuben Collins, photovoltaics researcher from the Mines Physics Department, and his group is to significantly improve the creation and transportation of electricity in materials and thereby shorten the time for solar energy to make a major contribution to world energy production.

Center researchers are working on unique approaches to the materials, including synthesis, novel characterization and computational modeling of the materials' properties. This effort is directed at developing a fundamental understanding of advanced materials, nanoscale architectures and novel concepts to harvest energy from the sun. If successful, these investigations should lead to substantial reductions in the cost of photovoltaic devices.

Andrew Herring from the Mines Chemical Engineering Department is leading the second group, which aims to develop an understanding of enhanced transportation of ions in solids, such as charged hydrogen atoms or oxygen-hydrogen molecules. Researchers are focusing on composite membranes that include both organic and inorganic components.

Because the transportation of ions in solids is fundamental to nearly every process involving the conversion of chemical to electrical energy, such membranes underpin many biological systems. They're crucial to a diverse array of energy-related applications including fuel cells, electrolyzers, batteries, electrochromics, chemical separators, membrane reactors and sensors. Center research in this area emphasizes design of composite membranes containing very small-scale structures that exhibit improved stability, operational range, impurity tolerance, efficiency of ionic collection, and selectivity for specific ions and atoms.

Each year, REMRSEC will select new research directions and support them through a seed grant program. The purpose of this program is to support work in emerging areas of renewable energy research that is high risk, but potentially offers high rewards. The initial seed grant is aimed at improving the storage of hydrogen or methane by using novel open-cage structures known as clathrates. Carolyn Koh from Mines' Chemical Engineering Department is coordinating this research, which involves the use of hydrate (water based) or silicon clathrate structures for the storage of hydrogen and methane.

alphavisions /iStockphoto

New summer research experience introduces undergraduates to renewable energy

Dozens of undergraduate students will have the opportunity to participate in REMRSEC's research during the summer through a newly established 10-week Research Experience for Undergrads (REU). Student participants were selected through a competitive process based on academic standing, faculty recommendations and personal statements of interest.

The students will focus on three research areas — photovoltaics, fuel cells and energy storage systems — in this hands-on program offering a full-time, high-level research experience that will address fundamental issues involving materials related to the science and technology of renewable energy.

For example, students working on photovoltaics will look for breakthroughs that could drive down costs, creating competition with energy derived from burning coal. Students researching fuel cells will look for breakthroughs in ionic transport that could lead to lower cost devices competitive with other forms of producing electricity. Students focusing on energy storage will look for breakthroughs that could lead to more efficient storage of fuels.

"Mines students can make a difference in our world's renewable energy needs," said REU director Chuck Stone, noting the average age of a NASA scientist when Neil Armstrong took that first historic step on the surface of the moon was 26.

Participants will receive a stipend of $4,500, attend scientific seminars, tour private companies and government labs involved in alternative energy technologies, and have opportunities to present their research results at a national conference.

"This is a very exciting new program for Colorado School of Mines, especially now when the development of alternative methods to generate energy is so critical to the future of our state, our country and the world," said Craig Taylor, REMRSEC director.

A MESSAGE FROM

Ken Salazar, U.S. Secretary of the Interior

Today there are brilliant, inspired innovators working to make changes as profound in our time as electricity and canals were in their time.

Colorado School of Mines is a model for how our nation's research institutions can lend their scientific expertise and their forward-thinking vision to the task of rebuilding our economy and setting our country on a path to a clean energy future.

No one institution, of course, can meet all the challenges we face. Each will lend a piece to complete the puzzle. Mines contributes an unparalleled, comprehensive and balanced spectrum of energy-related research — from conventional oil, gas and coal resources to renewable solar, wind, biomass and geothermal resources — and a mission to promote "stewardship of the Earth upon which all life and development depend." It is no wonder that Mines is a sought-after partner in research enterprises around the globe.

As a Coloradan, I am proud Mines is a member of the Colorado Renewable Energy Collaboratory, a one-of-a-kind collaboration with Colorado State University, the National Renewable Energy Lab and the University of Colorado. Together these partners are developing new energy technologies and working to transfer these advances as rapidly as possible to the public, creating jobs and boosting our economy.

As a U.S. Senator from Colorado, I initiated the collaborative concept, and now as Secretary of the U.S. Department of the Interior, I am gratified to see the progress of this extraordinary group, which also includes some of the world's largest corporations as research sponsors.

This magazine highlights other cooperative research efforts that are making our world better and safer for all — efforts that are tied to core missions of the Department of the Interior. One article tells the story of Mines' partnership with Salish Kootenai College, an accredited four-year college in Montana where students representing some 107 federally recognized tribes can earn degrees in computer engineering. Together they are addressing difficult problems in energy science research and teaming up on high performance computing. Mines is also involved in collaborative research projects with the U.S. Geological Survey, housed on the Mines campus.

The Department of the Interior's National Park System celebrates many of America's great inventors and innovators. The Edison National Historic Site honors Thomas Edison, who turned his dreams into inventions, including the phonograph, electric lights and motion pictures. The Erie Canalway National Heritage Corridor tells the story of one of North America's most successful and influential public works projects, the Erie Canal. Built in the early 1800s, the canal was an engineering marvel that made New York City one of the world's largest trade centers.

Today there are brilliant, inspired innovators working to make changes as profound in our time as electricity and canals were in their time. It's exciting to imagine America's energy future — indeed, what I hope is the very near future for some important scientific developments. Education and research, strengthened by our commitment and ingenuity, are the keys.

Join with me in congratulating Colorado School of Mines for the critical role it plays in reaching this new energy frontier.

Former U.S. Senator representing Colorado, as well as former Colorado Attorney General and former Executive Director of the Colorado Department of Natural Resources, Ken Salazar is the Secretary of the U.S. Department of the Interior, steward of the nation's land, water and energy; recreational and cultural opportunities; Native American lands; scientific research; and fish and wildlife. He and his family have farmed and ranched in Colorado's San Luis Valley for five generations.

Colorado School of Mines
1500 Illinois Street
Golden, CO 80401

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT