Colorado School of Mines

ENERGY AND THE EARTH

INNOVATIVE RESEARCH 2010

INNOVATIVE RESEARCH at Colorado School of Mines

The research agenda at Mines proceeds at a record clip and this edition of our research magazine gives a flavor of the progress. Mines is unique in that it is the only scholarly institution with a charter to enhance understanding of the earth, energy and environment. This focus puts us in the sweet spot of much of the nation's current research activity.

For example, the Potential Gas Committee recently released an unconventional gas reserves study, based on work at Mines, that received national and international attention and has been influential in changing the nation's energy debate on the path to a sustainable energy future.

We have the added bonus that Colorado has the largest concentration of national laboratories in the country and our interactions with the National Renewable Energy Laboratory (NREL), the United States Geological Survey, the National Center for Atmospheric Research, and the National Institute of Standards and Technology continue to expand.

We are fortunate to have Dan Yergin's essay as the epilogue to our magazine. Dan is perhaps the most celebrated and influential energy scholar and analyst in the country. He makes the cogent point that, although the funding for energy research is increasing, we need to maintain a coherent and steady policy. This clearly has not been the case for the past 30 years during which the levels and directions of energy funding have fluctuated wildly. But Mines has research centers that have gained international recognition over this time frame while maintaining steady trajectories. We believe one of the prime drivers for this success and longevity is our close coupling with industry. This coupling helps define grand challenges and coherent underpinning for research, and many Mines graduates are leading the charge from the industry side. Mines has positioned itself to be in the critical paths of major research challenges. Examples of this research pedigree are:

Reservoir characterization: Our theoretical and experimental research in subsurface imaging, properties and characterization has had a profound impact on the oil and gas industry over the past 25 years. We are now expanding these activities into carbon sequestration, geothermal, and unconventional oil and gas research. A goal is to understand subsurface fluid flow on all length scales — a grand scientific challenge.

Hydrates: These fascinating materials were a major problem for the gas industry and for more than 30 years our world-leading research has helped solve the blockage problems in pipelines. Hydrates are now attracting much attention in terms of energy resources and possible environmental issues and we are leading much of the U.S. university research.

Ferrous metallurgy: Our steel research center has been at the forefront of alloying technologies for 25 years and is one of the few remaining metallurgy centers in U.S. universities. It is now a leader in determining next generation steels for the energy economy in terms of transportation and generation.

Photovoltaics: We have collaborated with NREL, since its founding, on photovoltaic research and manufacturing, and have helped drive the formation of this industry. This continuing research is now driving the search for the next generation of high efficiency photovoltaic cells.

Resource economics: Our economic geology and minerals economics research has been a cornerstone of our portfolio. This work has impacted industry and government in terms of research policy and decision-making. The issue of strategic and critical resources is moving to the center of the energy and security debate.

These are just a few examples of Mines research programs that have thrived for decades and will continue to grow and support the needs of the country. Exciting newer programs that we can imagine growing to such long term prominence are bioscience and bioengineering, as well as high performance computation and simulation, which cuts across our entire research spectrum. Ultimately our success depends on talent, and our faculty and students are second to none. However, as Dan Yergin succinctly points out, we will also need all the support we can muster from government, industry and our alumni.

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 and chairs Lawrence Livermore National Laboratory review committees.

John Poate stands in front of "Yosemite," a painting by renowned Western landscape artist Albert Bierstadt, at the Denver Art Museum. The painting, donated to Mines by wealthy Colorado miner Benjamin Briscoe in 1938, was prepared for public viewing by the conservation staff at the museum and is on loan there through spring 2011.

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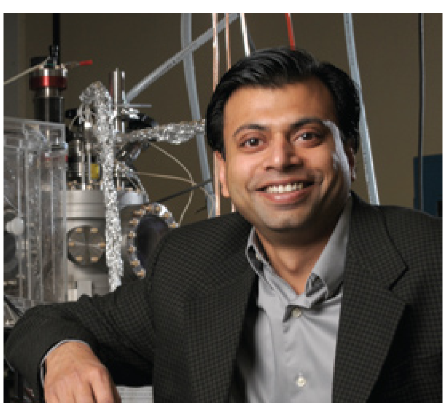

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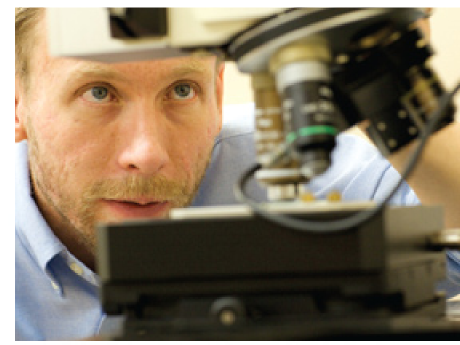

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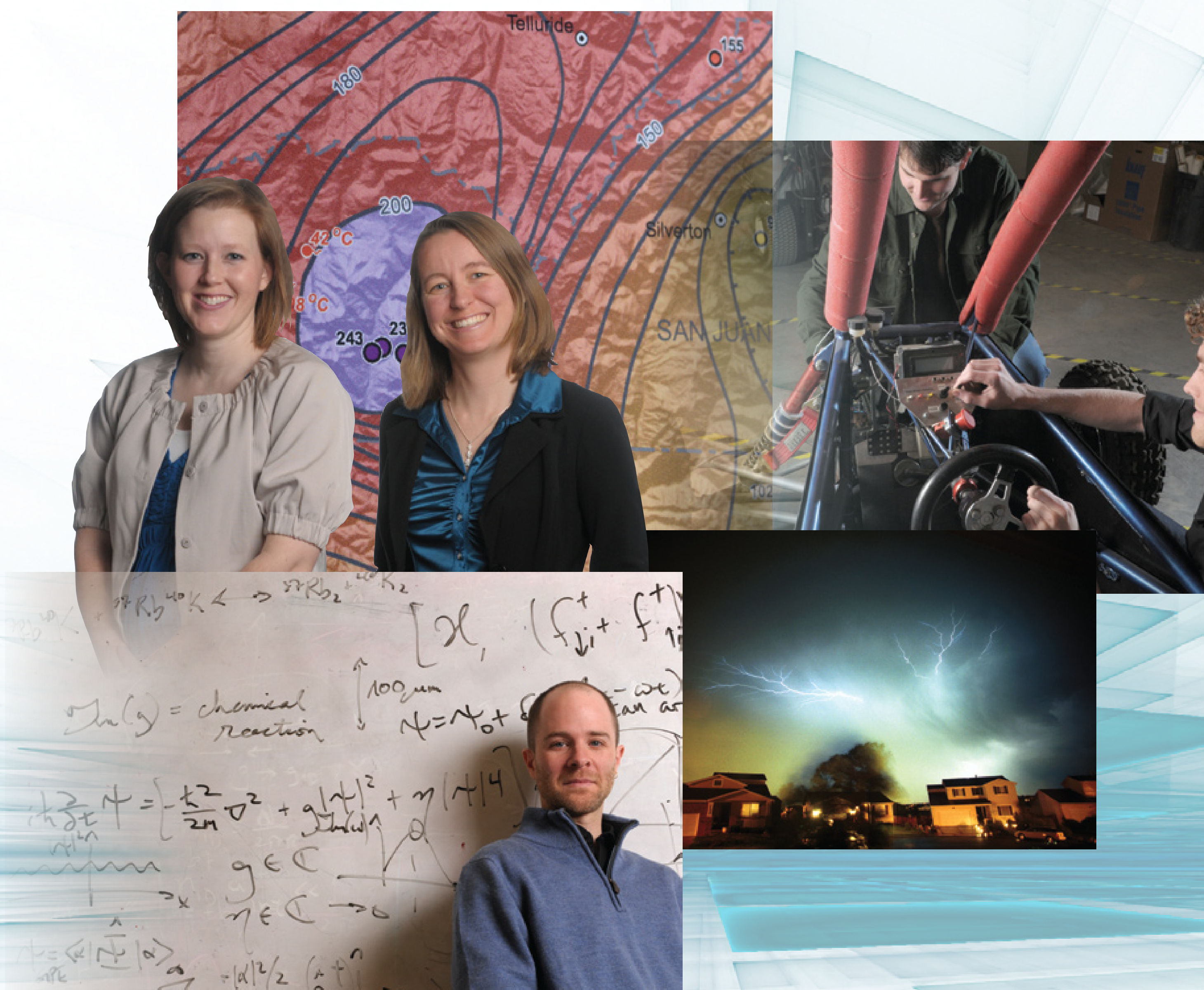

COLORADO SCHOOL OF MINES Snapshot

- Mines has a student body of nearly 4,700 (3,600 undergraduates and 1,100 graduates), a student-to-faculty ratio of 14:1, and an average undergraduate class size of 33 students.
- Entering freshmen have an average ACT score of 28 and most rank in the top 10 percent of their high school graduating class. The average GRE score for graduate students is 752.
- Mines ranked 34th in the "Top 50 Public National Universities" and 77th among "Best National Universities," both private and public, according to the 2010 edition of *U.S. News & World Report's America's Best Colleges*.
- Mines ranks No. 1 among state schools for starting salaries of graduates with bachelors' degrees, with a starting median salary of $60,000, according to Payscale.com, a global online compensation database.
- Mines has more than 140 student organizations, including the country's second largest student chapter of the Society of Women Engineers.
- Mines has 18 intercollegiate athletic teams, more than any other Division II school in Colorado.
- The Unconventional Natural Gas Institute — supporting multidisciplinary research in every area of unconventional natural gas exploration and development — was established at Mines in 2009.
- Mines is home to the $9 million National Science Foundation-funded Renewable Energy Materials Research Science and Engineering Center — a strategic partnership with the National Renewable Energy Laboratory, the University of New South Wales and Imperial College London.

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Geology Museum rocks, from Colorado to the moon

Bruce Geller

Established in 1874, Colorado School of Mines' Geology Museum continues to provide vital resources for campus researchers. The facility is known not only for its collections but also for its researchers' expertise in analyzing specimens.

As part of its mission to "inspire scientific curiosity through education and research," the museum's doors are open to the public, tour groups and the curious, who bring specimens in for examination. Museum Director Bruce Geller said the museum furnishes specimens for research when it can be done without causing specimen damage. Recent contributions have aided in a Mines geochemistry graduate student thesis, a U.S. Geological Survey isotopic investigation, crystal chemistry projects conducted by the Los Angeles County Museum of Natural History and the University of Colorado, and a spectroscopic study by a University of Arizona researcher.

"The Colorado School of Mines Geology Museum is a lightning rod for mineral donations and is becoming the fastest growing geology museum in the United States," said Brian Lees, a Mines alumnus and a leading mineral collector.

"This is no coincidence; mineral museums across the U.S. are feeling financial pressures from budget cuts as well as fundamental changes in museum structure. Over the past decade, several U.S. mineral museums have either cut down, or cut out funding for mineral exhibits. During this same period, the Mines Geology Museum has built a brand new museum, increased its staff, increased its donor support and expanded its image as a preeminent repository for top quality mineral specimens," Lees said, noting the museum has experienced a surge in new mineral and financial donations.

In the last year, the museum staff has used a portable X-ray fluorescence (XRF) analysis instrument to assist in their research efforts. As these investigations are the first carried out in a geology museum setting, it took some time to work out the kinks. After a period of intense testing, the XRF was used on bronze artifacts from India, in collaboration with the Denver Art Museum.

"We have benefited greatly from its use and have analyzed minerals and meteorites, as well as objects made from various alloys," Geller said. "We are currently studying whether the

Peters Photography

Kiefer Stumpp examines a piece of the fulgurite he discovered and donated to the museum.

instrument can identify trace element compositions in various specimens and objects, so we can establish geologically similar environments, or optimally, a specimen's provenance."

The main floor of the museum exhibits specimens from Colorado mines and features historic mining murals by Irwin Hoffman. The Special Exhibit Room displays prominent precious metals and invited displays by prominent collectors. Exhibits about radioactivity, fossils, basic geology, gemstones, meteorites, ultraviolet minerals and underground mining illumination are housed in the basement.

Two exhibits in the works include a display of what may be the largest group of fulgurite (lightning-fused sand) fragments discovered in Colorado, and a moon rock. NASA approved the loan of a specimen of lunar basalt collected during the Apollo 15 mission for the latter exhibit, which will compare and contrast lunar and terrestrial basalts.

"We are excited about the opportunity to highlight the roles some of our university faculty played in the space program and who continue to teach planetary science and astrogeology at Mines," Geller said.

Dave Scott, the astronaut who collected the specimen, will be invited to the exhibit dedication later this year. The lunar specimen is NASA's first long-term loan of a moon rock to any university science museum in the country.

Center for Innovation established by Newmont Mining Corporation

Recognizing the need for innovation in the mineral resource industry, Newmont Mining Corporation has committed $1.2 million to create the Center for Innovation in Earth Resources Science and Engineering (CIERSE), a new multidisciplinary center at Colorado School of Mines. The company will provide initial funding for three years.

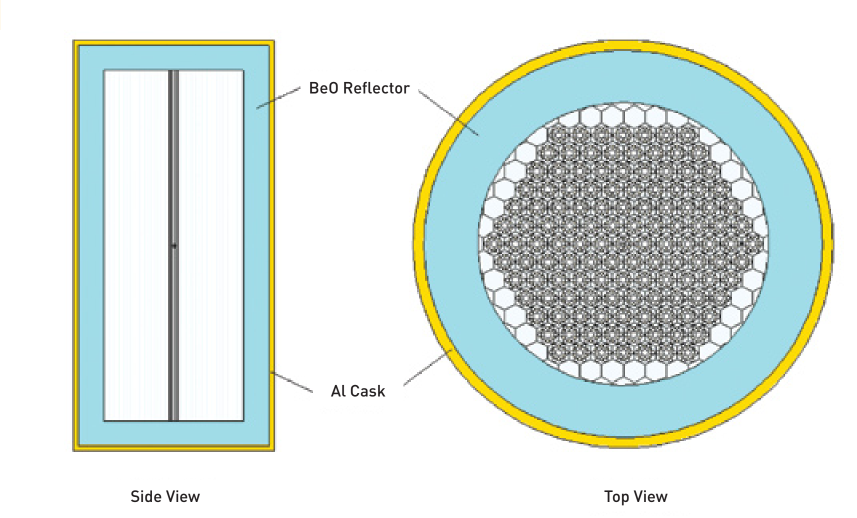
CIERSE, housed in the Mining Engineering Department, will focus on educating new professionals and developing innovative solutions to key challenges facing the mineral resource industry. It also will incorporate expertise from other Mines departments, including geology and geological engineering, geophysics and metallurgical engineering.

"Newmont's support for CIERSE will enable us to establish the center and attract significant research funding while providing our graduate students with opportunities to work with faculty, researchers and corporate partners to meet the critical needs of the mineral resources industry," said M. Stephen Enders, center director, research professor and Mines class of 1976 alumnus.

Newmont, headquartered in Colorado, is one of the world's largest gold companies with approximately 31,000 employees and contractors worldwide. Since the 1960s, Mines has enjoyed the support of Newmont Mining Corporation, first through scholarships for Mines students and later through support for students and research. The company also has contributed to the university's Edgar Experimental Mine in Idaho Springs, Colo.

"We know Mines is up to speed with the technical challenges our industry faces," said Jay Layman, Newmont's vice president for discovery and development solutions and innovation. "Their expertise goes beyond the leading edge of innovation. It's an expertise we as a company seek to leverage to help achieve our vision to become the most valued and respected mining company through industry leading performance."

Mines researchers work to make nuclear energy more viable



This diagram illustrates the structure of the reactor core nuclear fuel that produces the energy for various applications, heat processes, electricity and hydrogen production.

As the United States looks to shift from fossil fuels to cleaner energy sources, nuclear energy is poised to make a comeback. Nuclear energy provides the nation with nearly 20 percent of its electricity, and more than 70 percent of it is emission-free. In January, President Barack Obama asked Secretary of Energy Steven Chu to establish a Blue Ribbon Commission to evaluate nuclear policies with the aim of expanding the nation's capacity to generate nuclear energy.

One of the concerns with nuclear energy is managing used nuclear fuel. Researchers at Mines have been working to solve issues related to the back end of the nuclear fuel cycle along with many other challenges related to nuclear power. The interdisciplinary Nuclear Science and Engineering Program draws from researchers in the Department of Chemistry, Division of Engineering, Division of Environmental Science and Engineering, Department of Geology and Geological Engineering, Division of Liberal Arts and International Studies, George S. Ansell Department of Metallurgical and Materials Engineering, Department of Mining Engineering and Department of Physics. Their work focuses on fuel exploration and processing, nuclear power systems production, design and operation, fuel recycling, nuclear materials, storage and waste remediation as well as radiation detection and damage.

The program aligns researchers at Mines with researchers at the National Ignition Facility, Idaho National Laboratory, Oak Ridge National Laboratory and General Atomics. Their research could make nuclear energy production more efficient and increase the safety of reactors. For example, Jeff King, an assistant professor in the George S. Ansell Metallurgical and Materials Engineering Department (MME), is studying uranium-molybdenum alloy dispersion fuels to replace the highly enriched uranium fuel plates used in several research reactors. He's also examining the response of potential new reactor fuels and structural materials to irradiation. King is Mines' first faculty member dedicated fully to the graduate nuclear engineering program.

Other MME researchers working on nuclear projects include Brian Gorman and Ivar Reimanis, who are studying the properties of silicon carbide in coated particle nuclear fuels. Dave Olson, the John Henry Moore Distinguished Professor of Metallurgical Engineering, is researching uranium metallurgy for Oak Ridge National Laboratory.

Uwe Greife, a physics professor, is performing neutron-induced reaction measurements relevant to nuclear reactor performance and non-proliferation issues. The detection systems are being developed at Mines before being deployed at the Los Alamos Neutron Science Center. "The results will provide improvements to neutron propagation codes used in large-scale simulation of nuclear facilities," Greife said. The U.S. Department of Energy, Office of Nuclear Energy through the Nuclear Energy Research Initiative-Consortia and Nuclear Energy University Programs provide funding for the low energy nuclear physics group at Mines.

Zeev Shayer, a research professor in the Department of Physics, is working with General Atomics to develop a computational capability and simulation related to fusion technology that could improve future fusion power systems. In another project to address the need for smaller nuclear power units for space and terrestrial applications, he and Mike Worrall, a PhD student in the Nuclear Science and Engineering Program, are developing a new concept of small nuclear reactors. Based on High Temperature Gas Reactor technology, the proposed power unit will produce hundreds of kilowatts of energy. Advantages of the system include lower research and development costs, long operating time, lower power density and highly reliable system components.

"The proposed nuclear battery can also be utilized for onsite hydrogen production and heat processing for various industry and residential applications," Shayer said.

Drought creates 'water refugees' in Middle East

The Middle East is undergoing a water crisis that has forced hundreds of thousands of people in Syria and Iraq off their land and has turned 160 villages into ghost towns since 2007. Hussein A. Amery, an associate professor in the Division of Liberal Arts and International Studies, says the problem is the result of climate change, mismanaged water resources, population growth and changing lifestyles.

Amery, who is the director of Mines' International Political Economy of Resources master's program, teaches graduate and undergraduate courses on water politics and policy and on Middle East development. He has written extensively about these topics, including the book *Water in the Middle East: A Geography of Peace*.

Considered the cradle of civilization, the region dubbed the Fertile Crescent is flanked on the west by the Mediterranean and on the east by the Euphrates and Tigris rivers. Home to the first known Neolithic farming settlements, its fields in recent history were green most of the year, producing grain and supporting sheep and cattle. But since 2007, rainfall has diminished and a dire climate model from that year predicted ever-decreasing precipitation and streamflow shortages. While many Arabs fault the Turkish dams that limit the flow of water downstream from the Tigris and Euphrates, some Turks say Arab farmers use outdated farming techniques, wasting precious water that could sustain their populations.

After years of tension, Turkey, the upstream state, held talks with Iraq and Syria about how to manage the significant decline in water flow during the current drought. BBC radio interviewed Amery last fall about the drought, and he spoke on National Public Radio in January about the talks between the Middle East nations, saying it's a good start.

"It requires a new way of thinking about farming and irrigation," Amery said. "Traditional farmers in the Middle East apply large amounts of chemical fertilizers to fruit trees and irrigate by flooding their orchard, thinking that the more you give a tree, the higher its yield. That approach wastes water and suppresses yields, and excess fertilizers seep into the ground and make their way into the surface or subsurface water sources hence polluting them."

Amery says drip irrigation uses a "less is more" approach, boosts yields and could offer incentives for farmers to stay on the land. But he acknowledges new technologies require an initial outlay of capital that many farmers may not have. Government intervention likely would be required to create a change from traditional methods to those using new water-saving technologies.

Shriveled crops and barren pastureland have created "water refugees" — farmers who emigrate, seeking sustenance in newly-created shantytowns on the outskirts of cities, rife with criminal activities, where deep anger and frustration builds among the new refugees. Amery warns that social disruption at this magnitude does not bode well for social and political stability.

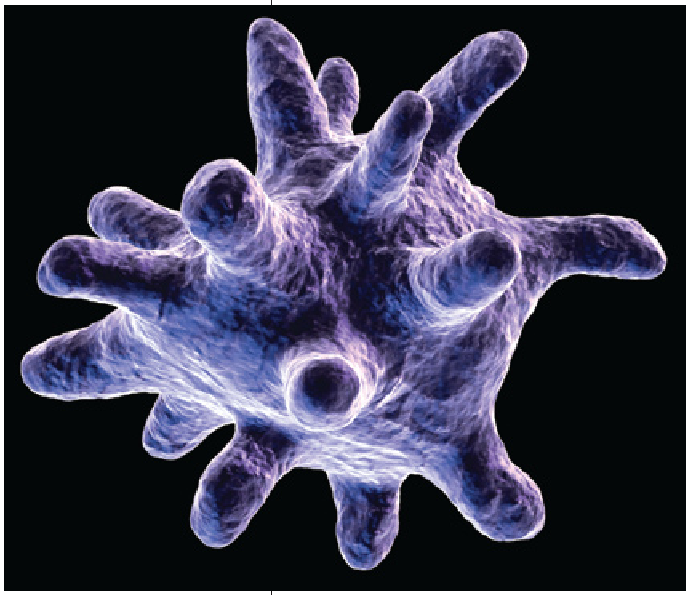
"Embracing water-saving technologies and introducing policy and pricing remedies could contain the potential political instability that aridity and future droughts may trigger," Amery said.

While he believes the current drought will end, water conservation is imperative in the naturally arid to semi-arid Middle East. Yet Middle Easterners are rapidly moving from grain-based to meat-based diets. "It takes some 15,000 liters of water to produce a kilogram of beef while it takes 1,500 liters to produce a kilogram of cereal," Amery said.

Maha Bounassif Amery

Hussein Amery is pictured in the desert town of Maaloula, Syria, north of Damascus.

Bioscience company reaches major milestones



Sebastian Kaulitzki | Shutterstock

In 2002, Kent Voorhees, a chemistry and geochemistry professor at Mines, took his rapid bacterial identification research in a commercial direction when he started MicroPhage, a bioscience company that develops and patents bacteria detection technologies.

Over the years the company found investors, opened a 5,000-square foot office in Longmont, Colo., and narrowed its focus to clinical applications for staphylococcus aureus (staph bacteria). MicroPhage recently made great strides in its research and release of a commercial test in the worldwide market. Among its recent achievements are the conclusion of a pivotal study, clearance to sell its first commercial medical diagnostic product in Europe and, pending FDA approval, marketing that diagnostic product in the U.S. by summer 2010.

The clinical study was one of the world's first tests designed to rapidly identify bacterial infections and antibiotic susceptibility without costly equipment. Using two small reaction tubes similar to home pregnancy tests, in just five hours the test identifies whether blood culture specimens are infected with staph and determine if the culture has methicillin resistance (MRSA) or susceptibility (MSSA).

"MicroPhage has done extremely well on its research," Voorhees said. "We are hoping that it will take off."

Looking ahead, MicroPhage is poised to ramp up production and staffing levels this year.

"Because Mines owns the patent rights and has exclusively licensed these rights to MicroPhage, the school could see a significant return on its initial investment," said William Vaughan, director of technology transfer at Mines.

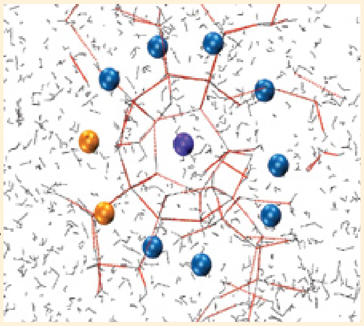
Supercomputer, scientists achieve super feat in hydrates research

Using the substantial power of the supercomputer "Ra" at Colorado School of Mines, the Center for Hydrate Research scientists captured the rare event of hydrate nucleation from methane and water by direct molecular simulation — a feat that has eluded the hydrate field for more than 20 years.

This achievement was featured in the Nov. 20, 2009, issue of *Science* magazine in a paper titled "Microsecond Simulations of Spontaneous Methane Hydrate Nucleation and Growth" by Mines doctoral graduate student Matthew Walsh, and center faculty and co-directors Carolyn Koh, E. Dendy Sloan, Amadeu Sum and David Wu.

Hydrates are at the forefront of efficient gas storage, reliable energy delivery and future energy resources. A full description of the molecular mechanism of hydrate formation would provide a better understanding of how hydrates are formed and controlled, impacting how gas hydrates are managed in flow assurance, utilized in energy storage and recovered as future energy resources.

"The Mines study in *Science* will accelerate the understanding of hydrate nucleation for other scientists, and the center has initiated collaborations with other leading researchers around the globe in order to fully understand this important phenomenon," said Wu.



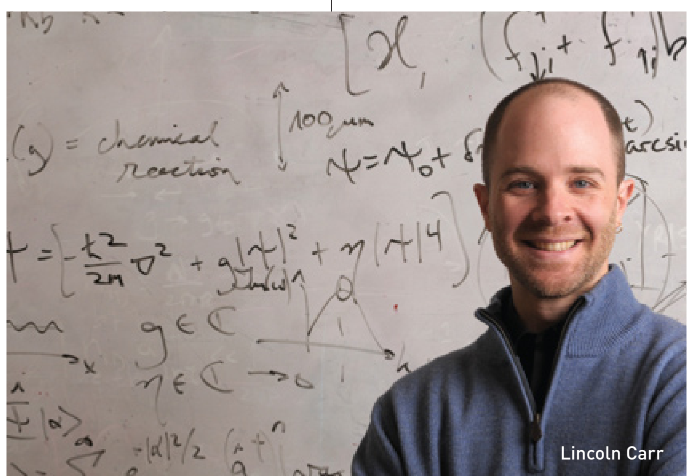
Center for Hydrate Research

In this molecular visualization of the initial intricate structure in the formation of hydrates, the colored spheres represent methane molecules, the red lines are hydrogen bonds between water molecules and the dark specks are water molecules.

Previously, molecular simulation of hydrate nucleation and growth had been hindered by short simulation times (on the

Physicists follow (ultra)cold front to foundations of science

In graduate school Lincoln Carr worked at the European Organization for Nuclear Research (CERN), where he studied ultra-hot quark-gluon plasmas in an effort to re-create conditions from the first microsecond of the universe. Today Carr, an associate professor in Mines' Department of Physics, is at the opposite end of the temperature scale — working with ultracold quantum gases that could hold the key to developing new quantum materials.



Lincoln Carr

Aided by the supercomputer dubbed "Ra" at Mines, the Carr Theoretical Physics Group works in three main fields: quantum many-body theory, nonlinear dynamics and artificial materials. Research in each area aims to bring about technological advances and contribute to the underlying knowledge base.

"A standing question in physics is how to transition from quantum things like electrons, which are best described by probability waves, to classical things like chunks of rock or water or people, which are best described by definite statements like, 'I am here, at this time, not moving,'" said Carr. "We know how to do this for one or a few particles, but are not really sure about the limits of quantum mechanics and the transition to the classical for many particles."

Understanding is growing rapidly as new developments occur. Just last year, there was a development in ultracold physics where ultracold atoms were assembled into ultracold molecules. It's an area Carr's group is quite excited about and is actively addressing. He says the importance of the field can't be overstated, noting that research in ultracold quantum gases was not only the subject of a 2001 Nobel Prize, but 10 Nobel laureates are working or recently have worked on the subject.

"Ultracold molecules are the next step beyond ultracold atoms, because they have new internal degrees of freedom and promise a totally new regime of chemistry," Carr said.

Last year a workshop Carr organized, "Quantum Simulation/Computation with Cold Atoms and Molecules," was conducted at the Aspen Center for Physics. There were 47 participants from all over the world, and 34 papers were produced as a result. "The work of theoretical physicists such as those at the workshop makes a difference in the world," Carr said, "because it develops a deep understanding of the foundations of science upon which technological progress depends."

"More important than improvements to enhance computer or aerospace technology," he noted, "is the fundamental insight of theoretical physicists, which changes society's deepest ideas about nature."

"Facilitating great science in this way is the best reward I could have," Carr said. He credits his students' dedication and enthusiasm as the main reasons he chose a university career. As a professor, he said his role "is equal parts creating great science and creating great scientists."

order of tens of nanoseconds), but the Mines research team observed methane hydrate nucleation by extending simulations two orders of magnitude longer than previous studies to achieve simulations of microseconds. While more research is necessary to obtain a complete picture, these simulations represent a substantial step toward understanding hydrate nucleation.

These simulations reveal an intricate microscopic mechanism for hydrate formation, a phenomenon described by Princeton University Professor Pablo Debenedetti as a "molecular ballet" in an accompanying commentary in the same *Science* issue. This molecular ballet involves the cooperation of water and methane to form a nearly symmetrical structure followed by rearrangement to allow formation of more methane-trapping water cages. This kind of information could allow companies to engineer physical and chemical processes to prevent (in oil and gas flow assurance or during energy recovery) or promote (in gas storage) gas hydrate nucleation.

"Scientific problems like this demonstrate how high-performance computational tools can transform our understanding of gas hydrate nucleation and growth, without which, precise molecular insight into the interactions and dynamics of water and methane molecules could not be foreseen from traditional experimental approaches," said Koh.

Future work will focus on different temperatures and pressures and use more statistically based methods to complete the molecular description of hydrate nucleation.

This study was supported by the National Science Foundation-Renewable Energy Materials Research Science and Engineering Center (NSF-REMRSEC) and CBET Division, the U.S. Department of Energy-Basic Energy Sciences, and the Mines Hydrate Consortium, which has been sponsored by BP, Champion Technologies, Chevron, ConocoPhillips, ExxonMobil, Halliburton, Multi-Chem Group, Nalco, Petrobras, Schlumberger, Shell, SPT Group, Statoil and Total. Simulations were carried out in the computational facilities at the Golden Energy Computing Organization at Mines using resources acquired with financial assistance from the NSF and the National Renewable Energy Laboratory (NREL).

On the verge of creating a mini fusion explosion

Lawrence Livermore National Laboratory

A NIF hohlraum. The hohlraum cylinder, which contains the NIF fusion fuel capsule, is just a few millimeters wide, about the size of a pencil eraser, with beam entrance holes at either end. The fuel capsule is the size of a small pea.

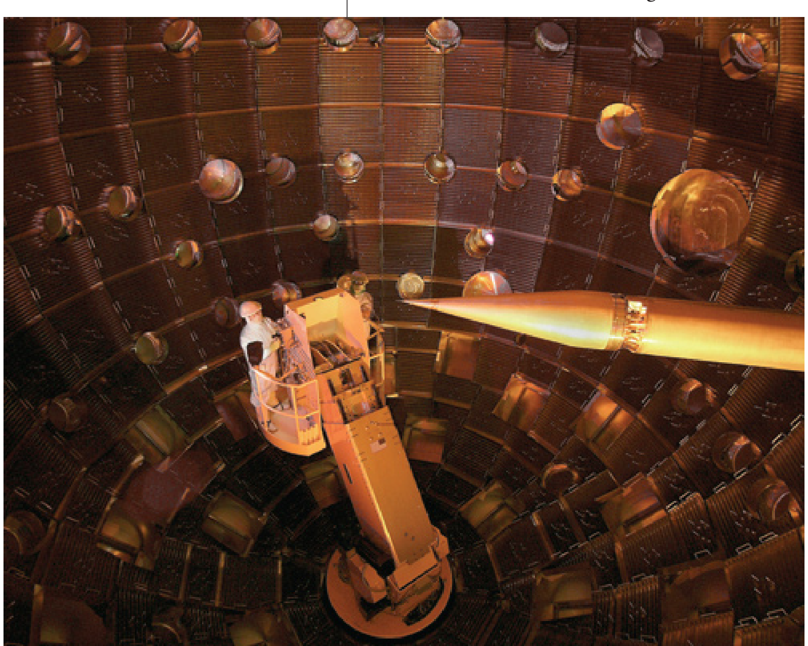
The eureka moment — the solution to a scientific problem that comes when the researcher was looking for something else — makes for interesting stories. More often the moment is the result of moving closer to the solution slowly, steadfastly day after day. That moment, or more precisely, a few picoseconds or trillionths of a second, is about to occur for Lawrence Livermore National Laboratory (LLNL) scientists.

Mines Research Professor George Gilmer is one of those scientists. Gilmer actually wears two hats: professor in the Division of Engineering and physicist with the National Ignition Facility (NIF) at LLNL — he splits his time evenly between the institutions.

The NIF laser and target area building at Livermore is a structure so large three football fields could fit inside. The complex experiments performed there required scientists and engineers to develop materials that could withstand NIF's extremely high energies and make improvements in pulsed-power electronics, innovative control systems and advanced manufacturing capabilities.

The NIF project is on the verge of creating a miniature fusion explosion — something that's never been done before. It will be the first time scientists create conditions akin to those in the sun.

The hitch so far has been in attaining ignition. Ignition is the reaction that occurs when a fusion event between two atoms in a group emits energy and/or particles that may cause other atoms to react. In this way the reaction spreads throughout the entire group. The process Gilmer and his colleagues are involved in takes a "target," a pea-sized spherical shell containing deuterium and tritium (isotopes of hydrogen) enclosed in a gold cylinder. Then 192 pulse lasers in two-foot-diameter tubes, all aligned and controlled by a single laser, zap the target. The laser beams impinge on the gold cylinder and produce x-rays that strip the outer shell of the pellet and heat it to millions of degrees. The fusion of deuterium and tritium forms helium. If it works, the energy released by this fusion heats up neighboring atoms enough for the process to self-propagate and produce an explosion.



Lawrence Livermore National Laboratory

The interior of the NIF target chamber. The service module carrying technicians can be seen on the left. The target positioner, which holds the target, is on the right.

Gilmer's research is in materials science modeling. The same skills he developed for 30 years at Bell Labs for AT&T is now helping the scientists at Livermore working on this multi-billion dollar project prepare for ignition by ensuring the loaded shell retains its spherical symmetry.

"The frozen deuterium and tritium form a neat little shell of uniform thickness inside the spherical shell. When the lasers ablate and compress the shell, it should end up about a thousand times smaller in volume and located in the center. If it's off center, one region will bulge out, it becomes unstable and you don't get the compression you need. A very important part I've been working on is understanding how to get uniform layers of these frozen gases on the inside of the shell," Gilmer said.

Numerical computer models aim to predict whether there will be enough compression for ignition to occur. NIF employs one of the most sophisticated computer control systems in government or private industry. LLNL also has some of the fastest computers in the world with more than a petaflop of available computing power to perform calculations. So far, the team's major accomplishments have been getting the 192 laser beams to fire and getting symmetrical compression of the fuel capsules. The next step toward fusion, anticipated in summer 2010, is to begin experiments approaching ignition with capsules containing fuel.

Applications for the research, which is funded by the U.S. Department of Energy, include basic science research such as understanding cosmic processes, large-scale clean energy production, improving nuclear reactor efficiency and nuclear weaponry. When the facility is operational, Uwe Greife, Mines physics professor, is planning to carry out astrophysical experiments.

"We have close ties with Livermore in many areas but none more pressing or exciting than the campaign for ignition. This is undoubtedly the greatest experiment underway in the world. Achieving ignition will be a true scientific milestone on the road to clean energy," said John Poate, vice president for Research and Technology Transfer at Mines.

Fuel cells take Mines professor to White House

Kirsten Boyer

Ryan O'Hayre, associate professor in the George S. Ansell Department of Metallurgical and Materials Engineering at Mines, has earned the Presidential Early Career Award for Scientists and Engineers (PECASE) for his fuel cell research. The award is the highest honor bestowed by the United States government on scientists and engineers in the early stages of their independent research careers. O'Hayre received the award during a ceremony at the White House in January, where he met President Barack Obama.

"The PECASE award is an amazing honor. As a Mines alumnus, I am particularly proud of the recognition this honor brings to our school and the fantastic research that is going on here," said O'Hayre, who credits his colleagues and students' talent along with the supportive and collaborative environment at Mines, the Colorado Center for Advanced Ceramics, the Renewable Energy Materials Research Science and Engineering Center, and the Colorado Fuel Cell Center for making the award possible.

"The trip to the White House was exciting especially because I was allowed to bring my wife and my mother along with me. My family deserves a lot of credit for supporting me through the years, so I was thrilled to have them along."

He and his family were treated to a White House tour and a reception at the Department of Commerce across the street from the White House. O'Hayre received a letter and an award certificate signed by the president.

"You have been selected for this honor not only because of your innovative research, but also for your demonstrated commitment to community service and public outreach," President Obama wrote in his letter to award winners and repeated in his speech at the award ceremony. "Your achievements as scientists, engineers and engaged citizens are exemplary, and the value of your work is amplified by the inspiration you provide to others."

O'Hayre already has made remarkable strides in fuel cell research. Within five years of earning a PhD from Stanford, he helped achieve a scientific breakthrough that makes fuel cells more economically feasible, wrote the majority of the leading college textbook *Fuel Cell Fundamentals*, and invented a technology for measuring electrochemical phenomena at the nanoscale.

O'Hayre explains that devices such as fuel cells, solar cells and thermoelectrics produce electricity by converting a primary energy source such as fuel, light or heat into a flow of electrons. Energy from the source is passed along to the electrons constituting the electric current.

"Despite the successes brought about by the incorporation of nanostructured materials in fuel cells, solar cells, and other devices, we are still far away from possessing a solid understanding of what is really going on at the nanoscale," O'Hayre said.

While he's been working toward a greater understanding since his days at Stanford, he now foresees the intersection between materials science and nanotechnology for energy conversion applications as one of the most scientifically interesting, socially valuable and technologically fruitful areas of research over the coming decades.

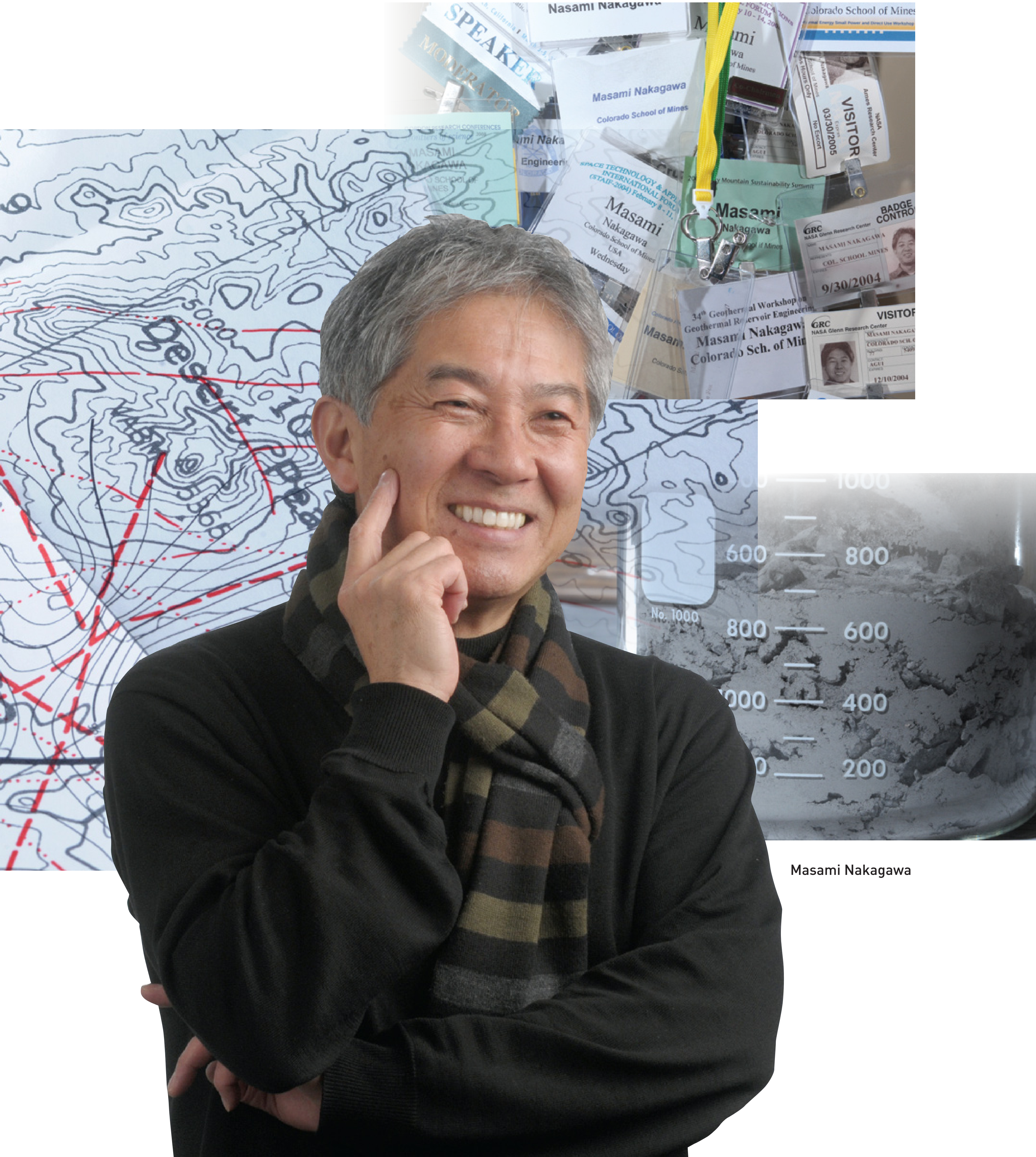
"Nanoscience introduces powerful and virtually untapped new dimensions to energy research," he said.

Winning scientists and engineers receive up to a five-year research grant to further their study in support of critical government missions. O'Hayre will use the grant to support his research on advancing fuel cells in collaboration with colleagues at the National Renewable Energy Laboratory. By using chemically functionalized nanostructured materials to improve energy conversion technologies, O'Hayre hopes to magnify the catalytic activity of platinum that powers fuel cells. If successful, the technology could be applied to other energy conversion technologies as well.

Applications for the research include portable power generation for laptops, cell phones and for larger-scale operations such as NASA's space shuttle program and the U.S. military.

From left: John Holdren, director of the U.S. Office of Science and Technology Policy and recipient of a Colorado School of Mines honorary degree, Ryan O'Hayre and Zachary J. Lemnios, director of Defense Research and Engineering at the Department of Defense (DOD). The DOD Army Research Office sponsors O'Hayre's PECASE research.

Geothermal Energy



Masami Nakagawa

Ever-present resource for ever-increasing needs

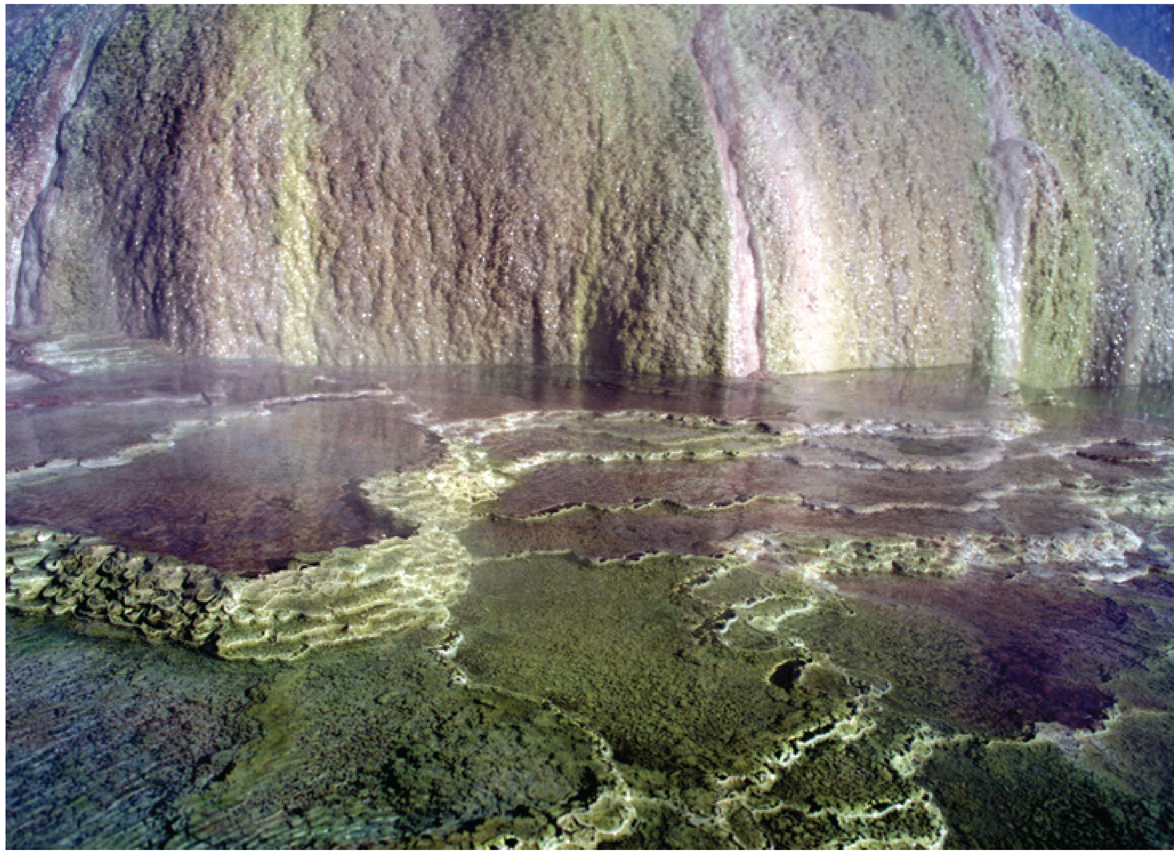
Deep HEAT

When it comes to energy, Masami Nakagawa, a professor in Mines' Department of Mining Engineering, often finds answers not in front of, but below him. Nakagawa researches geothermal energy — the power extracted from heat stored in the earth.

"If we know how to utilize the geothermal energy that is available at either very shallow depths or at great depth, then we can significantly contribute to the nation's ever-increasing energy need," Nakagawa said. "Unlike other renewable energy forms such as solar and wind, geothermal energy is always there (not intermittent) and can supply the ever-needed consistent base-load."

His research, assisted by a number of graduate students, focuses on geothermal energy available a few meters deep, called "ground source," as well as deep magmatic heat found several kilometers below the earth's surface. Ground source heat pumps can be used just about everywhere in the U.S. to heat and cool buildings, and could reduce electricity bills by as much as 60 percent. Nakagawa explained that ground temperature increases about 2.5 to 3 degrees Celsius every 100 meters in depth toward the hot center of the earth.

"This means if you go deep enough, the ground becomes hot enough so that if you inject cold water there, then you can recover it as hot water or steam to turn a turbine," he said.



NREL

This particular form of utilizing geothermal energy is called Enhanced Geothermal Systems. In November 2009, Nakagawa and Marte Gutierrez, the James R. Paden Distinguished Professor of Civil Engineering, were awarded an $860,600 Department of Energy (DOE) grant to study enhanced geothermal reservoirs. They will create and validate a prediction model depicting how fluids will act if injected into a well.

Nakagawa described the project as a complex, cutting-edge simulation and validation to discover how injected water fractures rock under extreme pressure and temperature and also how it travels through complex pathways of fractured rock. Additionally, the researchers will conduct a laboratory experiment to simulate in-situ behavior of how rock is fractured.

One challenge for U.S. geothermal researchers is much of the talent that was in the field in the 1970s and 1980s is gone due to lack of federal funding. But today's researchers have the advantages of sophisticated geophysical techniques and mathematical and simulation tools that were unavailable 30 years ago. They can revisit previously explored geothermal sites and re-interpret them using today's technology.

Geothermal resources can be especially beneficial to isolated communities by providing base-load energy. Nakagawa said a geothermal system could fuel a small power plant capable of generating as little as 250 kilowatts of electricity for a small community. He's taking this message on the road in his "12 in 12" campaign. He'll deliver a dozen geothermal workshops in 12 Colorado mountain communities with geothermal potential over the next 12 months.

Nakagawa also directs Mines' new Geothermal Academy. Its mission is to create strong educational programs so faculty members and students can gather, analyze and disseminate data about geothermal energy to the public and policy makers. The academy received a $245,800 DOE grant to be a clearinghouse for ground-source heat projects. Nakagawa is networking with other geothermal researchers throughout the world to pool their knowledge. So far, he is collaborating with several groups in Iceland and Japan in addition to several schools and national labs in the U.S.

He's also developing a partnership with the Lummi, an American Indian tribe of the Coast Salish group, which resides primarily in Washington. Because ground source heat pumps are non-invasive and environmentally friendly, the Lummi are very interested in the technology.

"I can envision installing many of these units in houses on Indian reservations and developing educational programs to help them create jobs within their own communities. I have always been interested in sustainability and wanting to develop sustainable or renewable communities. Geothermal energy can help bring me one step closer to realizing this goal," Nakagawa said.

He recently received a joint appointment with the National Renewable Energy Laboratory, the first official Mines-NREL joint appointment. Nakagawa will spend half of his time with the geothermal group at NREL, where together they'll conduct various research projects related to low-temperature geothermal resources and ground source heat pump technologies.

In January, Nakagawa helped lead Mines' second annual Geothermal Symposium, with 233 registered participants from 10 states, as well as from Iceland, Japan and the Philippines. They discussed geothermal projects in their regions and other parts of the world at the symposium sponsored by the Colorado Energy Research Institute and the Governor's Energy Office.

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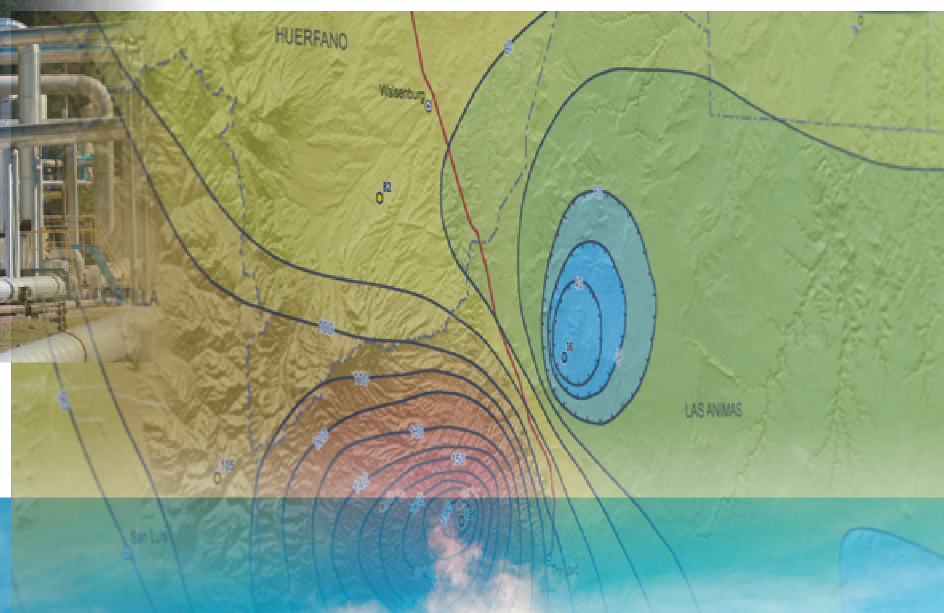

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Will supply of minerals meet demand for materials?

Minerals MATTER

Mineral-based materials are ubiquitous — aluminum in jet aircraft, steel in bridges and buildings, and lead in batteries. The emergence of new technologies and engineered materials could rapidly increase demand for some minerals, previously used in relatively small quantities in a small number of applications, such as new applications of lithium in automotive batteries, rare-earth elements in permanent magnets and indium and tellurium in photovoltaic solar cells. At the same time, the supplies of some minerals are becoming increasingly fragile due to more fragmented supply chains, increased U.S. import dependence, export restrictions by some nations on primary raw materials, and increased industry concentration.

Rod Eggert, professor and director of Mines' Division of Economics and Business, analyzes "critical minerals" — minerals that are essential in use (difficult to substitute away from) and subject to supply risk.

Rare-earth elements are one such example. A family of 15 elements, rare earths play an essential role in hybrid vehicles, wind turbines, compact fluorescent light bulbs and other emerging energy technologies because of critical properties they provide to magnets, catalysts, metal alloys and other applications. Typically used in small quantities in specific products, rare earths have few or no known substitutes in these applications.


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MINERALS, CRITICAL MINERALS, AND THE U.S. ECONOMY

Rod Eggert

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More than 95 percent of the current supply of rare-earth elements comes from a small number of mines in China, where exports are expected to decline in the coming years as Chinese domestic use of rare earths increases. Potential supply shortages could last a decade or longer if demand surges due to expansion of emerging energy technologies. Although there are many known, undeveloped geologic deposits of rare earths in North America and elsewhere, it takes five to 10 years to bring new mines into production.

In a presentation organized by the Mining and Metallurgical Society of America earlier this year, Eggert offered an analysis of critical minerals that combined his personal views and those of the committee he chaired two years ago for the National Research Council, whose views were published in *Minerals, Critical Minerals, and the U.S. Economy* (National Academies Press, 2008). The committee examined a range of issues concerning the evolving role of non-fuel minerals and the potential impediments of mineral supplies to the U.S.

"The possible impacts of supply restriction are higher mineral prices and physical unavailability. The economic consequences could lead firms to postpone building or to not build at all. For industry, this could mean lower output and profitability and slower growth in emerging applications. None of this, of course, would be good for the U.S. economy," Eggert said.

The 2008 committee made three recommendations for the federal government. First, the committee said the federal government should enhance the types of data and information it collects, analyzes and disseminates on minerals and mineral products, particularly those that are or may become critical. Important information gaps include reserves and subeconomic resources, byproduct and coproduct primary production, stocks and flows of materials available for recycling, in-use stocks of materials, material flows and materials embodied in internationally traded goods.

Second, the committee recommended the federal government expand the authority and autonomy of the agency responsible for collection and dissemination of information on minerals and materials.

Third, the committee said federal agencies should develop and fund activities to encourage U.S. innovation in the area of critical minerals over the entire lifecycle of materials starting with mineral exploration and extending through mine development, mineral processing, materials engineering and ending with recycling. The discussion of this final recommendation included the idea of establishing cooperative programs involving academic organizations, industry and government to enhance education and applied research.

"We are not about to run out of mineral resources. Rather, we are moving from lower-cost to higher-cost resources. For some minerals the location of current production is geographically restricted, leaving users vulnerable to impeded supply. As for timeframe, in the short run (up to a decade), supply risk is really all about the commercial and political risks associated with current production facilities. In the long term, however, mineral availability is governed by geologic availability and technological capabilities," he said.

"A key to responding to these limits on mineral availability," Eggert said, "is federal policy that facilitates innovation, which tends to be underfunded by the private sector because the benefits of basic research and development are diffuse, often far in the future and uncertain."

Water interactions — on land, in the atmosphere and below the surface

Taking on WATER

Attracted by the school's collaborative environment, Reed Maxwell came to Mines last year after working the previous decade at Lawrence Livermore National Laboratory. He's an associate professor in the Department of Geology and Geological Engineering, where he researches connections within the hydrologic cycle. Taking into consideration water from beneath the ground's surface, on the surface, and in the atmosphere and atmospheric conditions, Maxwell looks at how each component of the hydrologic cycle influences the others.

He's most concerned with solving water resource issues by better understanding the processes that govern the movement and quality of water. Because of the complexity of the issues and the many variations that must be examined, Maxwell has developed a suite of computer models that draw on novel numerical methods, parallel-processing and high-performance computing.

"We've run computer simulations on as many as 16,000 processors. That makes the simulations somewhat more complicated because we have to coordinate all the interactions between the processors to solve these problems, which necessitate these complicated approaches," Maxwell said, noting his team uses supercomputers from all over the world as well as Mines' own, dubbed "Ra," running in parallel.

Reed Maxwell

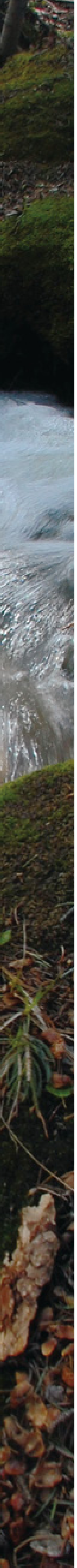
He described the computer experiments as being similar to virtual worlds. The numerical models may be imperfect, but they give researchers insight into how hydrologic connections and interactions work. That information feeds into Maxwell's research, particularly in the projects focusing on impacts and feedbacks of changes in climate and water resources.

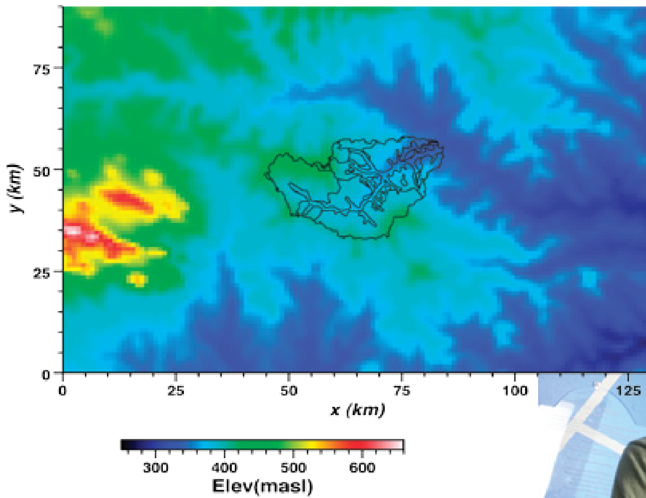
"What's somewhat unique about the research I do is that we actually look at interactions. In nature, there isn't really a clear distinction between the atmosphere, the land surface and the earth's subsurface. It's really all one coupled system. If you make a change in one part of the system, the entire system responds," he said.

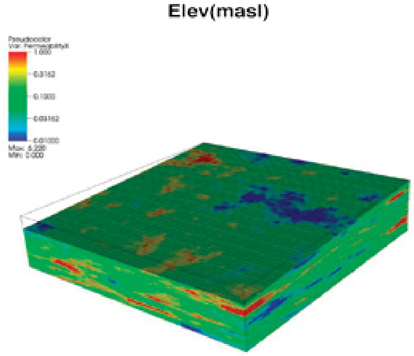
Maxwell said he's always been drawn to interfaces between systems. While many scientists focus on a particular piece of the puzzle, surface water for example, he's more interested in the interactions and connections along the artificial boundaries often drawn between systems. The pieces don't always fit together in a simple way. How they do fit, or don't as the case may be, has important implications for issues like climate change.

His research has a variety of applications. In a newly funded project, Maxwell is looking into the underground sequestration of carbon dioxide and determining the potential for carbon dioxide leakage into groundwater, which could pose risks to drinking water quality and health. In addition to examining the hydrologic cycle, the interactions between the natural system and the engineered system are important in a project like this. The same modeling platform used for determining connections in the hydrologic cycle is used to understand how carbon dioxide might impact water quality.

In another project funded by the Department of Energy (DOE), Maxwell is using fully coupled models of the subsurface, land surface and atmosphere to predict wind patterns. The information could tell wind farm operators whether to ramp up or ramp down wind production. In previous projects, Maxwell has developed models that







From left, Reed Maxwell, graduate and post doctoral students Erica Siirila, Shadi Moqbel, John Williams, Ian Ferguson, Steve Meyerhoff and Adam Atchley

show the interplay between groundwater and land-surface energy processes, which subsequently impact winds, temperature and moisture movement in the lower atmosphere. This interplay is useful in diagnosing watershed response and feedbacks to a changing climate.

While Maxwell's work is on the research side, the applications are often on an operational side. His work improves models that show how large, complex systems work. Once there is significant improvement in the physical description of these systems, then the models migrate toward the operational side of things. For example, Maxwell is in the early stages of an end-to-end hydrologic study of the San Joaquin watershed, which encompasses a large portion of California's Central Valley. The scenarios and "what if" type planning of the model could eventually have direct implications for the water district's mid-to-long-range planning.

"I think it's exciting when you can try to understand a system that's been studied for a long time. It's a very accessible system; it's the physical world. Everybody thinks about weather and rainfall and the water they drink, but people tend not to think about how these systems interact. There are a lot of very interesting and satisfying scientific questions there. It's interesting to have research that's both scientifically satisfying and also has a very applied end point in applications that are readily available to water managers, carbon services companies or wind energy companies."

Maxwell's work is interdisciplinary and collaborative. His collaborations include the carbon dioxide sequestration project with project investigator John McCray, director of the Environmental Science and Engineering Division, and strong collaborations with the National Center for Atmospheric Research, Lawrence Livermore National Laboratory, National Renewable Energy Laboratory and with universities, among them the University of Colorado-Boulder, University of California-Berkeley, University of Florida, University of Maryland, University of California-Davis, Penn State University, Bonn University in Germany and University of Padova in Italy.

"It's a lot easier to collaborate externally at a university than a national lab. You have an idea, e-mail your colleague, write a proposal, get it funded and you do it. There are zero barriers to collaboration. It's a really satisfying environment to work in and the research administration at Mines does many things to foster a collaborative environment. It's really a tremendous strength of Mines," Maxwell said.

Maxwell's projects receive funding from the National Science Foundation, Environmental Protection Agency, three branches of the DOE and from the Inter-American Development Bank, a Latin American bank similar to the World Bank. Students play a vital role in the research.

When he thinks about the future, Maxwell said he sometimes thinks he's just scratching the surface of understanding the hydrologic cycle and answering fundamental questions. While he's been looking at connections and interactions for many years, one of the directions he's going is research that "crosses scales."

In terms of downscaling, he said this means "taking what happens at the global scale, for example climate changes and shifts that are predicted by global models, and trying to understand how they would impact local resources and hydrologic conditions and how they would affect water management choices.

Trying to scale up is another really big question, he said. For example, the onset of drought is driven by large-scale climate processes.

"How likely a drought is to stick around, how long or severe a drought will be – these sorts of things are driven by local conditions, but may feed back on larger-scale processes. Investigating the interplay between local and large-scale processes is a very exciting direction for my research."

Wind Energy Resources

Forecasting and harnessing the wind

Current ENERGY

The question isn't just whether or not the wind is blowing, but also how to predict and control the wind energy resources useful for generating electricity.

Wind could supply as much as 20 percent of the nation's electricity according to the federal research lab Battelle Pacific Northwest Laboratory. Two Mines professors are researching ways to make wind energy a more viable option in the U.S.: Amanda "Mandy" Hering is an assistant professor in the Department of Mathematical and Computer Sciences, and Kathryn "Katie" Johnson is the Clare Boothe Luce Assistant Professor in the Division of Engineering.

"Wind can benefit the world as a greener source of energy compared to traditional fossil fuels. It won't ever make up the entire solution because of its intermittency, but it will absolutely be a part of the solution. Relying on home-grown energy like wind and solar can also reduce our dependency on foreign fossil fuel locations," Johnson said.

Johnson's research interests are centered on control systems and applications. While many control systems engineers who work on wind energy applications have focused on the load reduction side of the problem, Johnson has also worked on increasing energy capture via control. She has also tested controllers on a 600 kW turbine at the National Renewable Energy Laboratory (NREL), which she said is critical to verifying operation of newly developed controllers.

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NREL

Johnson is the Mines site director for the Center for Research and Education in Wind (CREW), a joint effort of Mines, the University of Colorado, Colorado State University and NREL. CREW is working to make Colorado a prime U.S. location for research in wind energy, which is the fastest growing energy source in the world. This unique research partnership, the Colorado Renewable Energy Collaboratory, allows companies and organizations to become members of its research centers and access collaborative institutional research capabilities.

"The best thing about wind energy research is its multi-disciplinary nature. I love to learn new material in different areas of engineering, science, and even economics, business and law. I also enjoy doing research that can contribute to a greener energy future," Johnson said.

Her wind energy control projects include a study to assess the value of a continuously variable transmission in a small wind turbine, a project to determine which loads cause the most damage in utility-scale wind turbines and use control to reduce these loads, and a project to improve the energy capture of wind farms using coordinated turbine control. In another project, she's working to implement feed forward control, which in this case is control based on measurements available from sensors looking upwind from the turbine. Johnson said all of these projects have the ultimate goal of reducing the cost of wind energy by reducing the initial capital costs, increasing the lifetime of a given turbine or increasing the energy capture.

In December 2009, she was selected as a participant for the 2009 DAAD Science Tour on Renewable Energy in Germany as a result of her efforts to create collaborations in wind energy research. Doctoral students Na Wang and Geraldine Fritsch assist Johnson in her work, which receives funding from the National Science Foundation, NREL, the Department of Energy and industry. In the long term she wants to expand her research to study hybrid systems that combine wind, solar and storage devices.

Hering just started working at Mines in fall 2009, and she's already hard at work on projects related to wind modeling and forecasting. She said although not many statisticians work on problems related to wind energy, there are many problems for which statistical tools can be applied. There are many time-series and space-time statistical modeling approaches that haven't yet been adapted for the wind energy forecasting application.

She works on developing statistical models for short-term wind speed forecasting. Numerical weather prediction models produce forecasts at three hours ahead and beyond, but models must be very fast to make predictions in the zero-to-three-hour range. Not only do statistical models produce a forecast, but they also include information about how certain that forecast is. Since wind power cannot be stored cost-effectively, it must be used as soon as it enters the electrical grid. This means utility managers must constantly balance the supply and demand of electricity. Short-term forecasts help them plan for the amount of wind-generated electricity they can expect so they can maintain that balance.

The U.S. can learn much from Denmark. After investing in wind for 30 years, Denmark has the world's highest percentage of electricity demand met by wind energy. Government subsidies in 1979 spurred that country's wind energy industry, and according to a 2009 *TIME* magazine article, Denmark gets 19 percent of electricity from wind. Hering benefits from that expertise through collaboration with a colleague at Denmark Technical University. She continues to work with her advisor, Marc G. Genton, a professor of statistics at Texas A&M University, and she works with researchers in the Geophysical Statistics Project and the Research Applications Laboratory at the National Center for Atmospheric Research (NCAR).

Master's student Megan Yoder is developing models to forecast an increase or decrease in wind speed along with a probability of that increase or decrease. Hering also has begun to investigate the role that wind direction plays in making a wind power forecast. She plans to develop a fully statistical space-time model for short-term wind speed forecasting, and in collaboration with researchers at NCAR, she's looking at the impacts of climate change on wind resources.

"I really enjoy applying statistical methods to real-world problems. It's very nice when you can see your work make a tangible difference. In particular, environmental problems have always been an interest for me, so it's great to work at a university that has a similar mission and in an area of the country that is rich with researchers working on problems related to the environment," Hering said.

Strategic Enterprises

Nigel Middleton

Small university, worldwide community, universal mission

Into INNOVATION

Colorado School of Mines' focused mission — creating solutions related to earth, energy and environmental challenges — has a global impact. And with this riveting opportunity, comes a unique responsibility.

Through the new Office of Strategic Enterprises (OSE), Mines' reach beyond its home campus to the rest of the world is intensified. With the university's concentration of talent, curricular programs, research portfolio and track record in outreach, Mines can now contribute more extensively to critical scientific innovations and to the worldwide quest for technological advancements. OSE is headed by Nigel Middleton, Mines senior vice president.

"Mines is a specialized university but with a versatile quantitative education. Our graduates are successful. We have an international reputation with a global network, and we already have numerous industry, government and academic partnerships," said Middleton.

With this solid foundation of long-standing strengths — as well as the incorporation of Mines' highly regarded Office of Special Programs and Continuing Education, directed by Gary Baughman, and the progressive Petroleum Institute in Abu Dhabi — the OSE has taken shape.

OSE's developing mission is to bring Mines' educational and intellectual resources to the world and enable professionals from around the globe to learn from Mines — whether in a classroom on the Golden campus, a laboratory in Kazakhstan or a living room in Houston. The goal is a distinctive "anywhere, anytime" approach to learning in a fast-paced, changing world.

Middleton has identified a number of potential project areas — enhancements of existing programs as well as the initiation of new programs — including executive and corporate training, non-degree courses, summer intensives and an international academy for energy sector faculty and others. Professionals needing continuing education will find short-term and part-time offerings, targeted training, off-campus programs and certificate courses. The multitude of planned for-credit and non-credit options will make it easier for professionals to craft programs fitting their busy schedules while increasing their value in the workplace.

Another OSE action item is to reach out to prospective universities on different continents to initiate partnerships that could benefit from Mines' academic capabilities in resource or energy development. Advancing Mines' global mission in other countries, OSE will increase opportunities for international researchers to study at Mines, and for Mines researchers to work at international facilities.

"In just a few years, the existing programs we're now expanding, and the new ones we're planning to launch, will be thriving, mainstream activities for Mines. We're ready and the time is right," said Middleton.

Hossein Kazemi holds the Chesbro' Distinguished Chair in Mines' Petroleum Engineering Department and is a research partner with the Petroleum Institute.

University Development

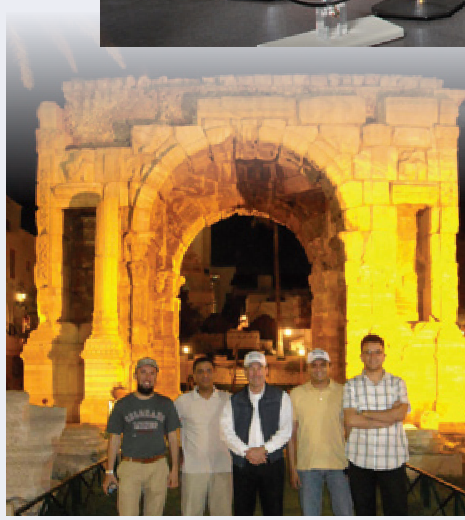
Mines has been the principal academic partner to the Petroleum Institute (PI) since first advising a group of companies, led by the Abu Dhabi National Oil Company, to start a technical university in Abu Dhabi, United Arab Emirates. That was 2001, and now the PI has graduates applying their skills in the workforce and continues to enroll approximately 1,100 students, with undergraduate degree offerings in petroleum engineering, petroleum geosciences, chemical engineering, mechanical engineering and electrical engineering.

Recently the PI established a graduate program leading to master's degrees, and Mines and the PI agreed to engage in joint research activities 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
- Instructional pedagogy

Given the success and experience of this academic partnership, OSE is currently exploring further possibilities for university development and affiliations in other parts of the world.

Current Enterprises



For years working professionals have taken advantage of Mines' **short courses and conferences** to keep their job skills current and remain abreast of recent technical developments in their respective fields. A wide range of subjects are addressed though these offerings, including economics, refining and natural gas processing, recycling metals, tight gas sands, tunneling technology and intensive petroleum engineering programs. Conferences include the annual Oil Shale Symposium as well as international events addressing astrophysics, underwater welding, metallurgical processing, occupational hazards, mining history and a host of others.

Mines' **International Institute for Professional Advancement (IIPA)** offers customized education and training programs for individuals, government professionals, corporations and multi-national organizations on the Mines campus and at sites around the world. Technical short courses have been taught in China, Egypt, Libya, Myanmar and many other countries, while professionals from around the globe have attended customized educational programs on the Mines campus. The IIPA also enables Mines faculty members to assist other universities around the world to enhance their engineering curricula, develop new academic departments, and even establish new institutions within their countries.

More than 2,000 **K-12 teachers** rely each year on Mines to provide outstanding content-based courses in the areas of science, math and technology. These courses, for which the teachers may earn credit toward re-licensure, often include hands-on experiences and practical applications which the teachers can take back to their classrooms. Some courses are taught on the Mines campus, others on the lands and waters of the West, and still others outside the U.S., including Scotland, Mexico and the Galapagos Islands. The Mines **Teacher Enhancement Program** is the largest such program in Colorado and one of the largest in the U.S.

The largest of its kind in the western U.S., the **Mine Safety and Health Training Program** conducts training activities, creates new training materials, and cooperates with other universities, state agencies, mining organizations, and the mining industry to enhance the safety and health of those who work in the mining industry. Programs also include customized underground rescue courses for first-responders, including those from fire departments throughout the U.S. and the U.S. military. The program is also developing a Mine Rescue Simulator which promises to dramatically improve the efficiency and safety in future underground rescue operations.

Founded in 1978, the **Energy and Minerals Field Institute (EMFI)** conducts field programs that familiarize government policymakers with the realities of energy and mineral production, processing and utilization throughout the western U.S. Participants include policymakers from executive departments and agencies; congressional committees, organizations and personal staffs; and personnel from the state governments of the states visited. Addressed are geologic, technical, environmental, economic, social, institutional and political aspects of energy and mineral development.

In addition to actual site visits, meetings are arranged with community groups, environmental organizations, professional societies, and others impacted by current or proposed resource development. It's a "kick the tires" experience, as Director Gary Baughman likes to say, with EMFI *facilitating*, not *advocating*.

A recent EMFI participant commented, "I've never been on any field trip that even remotely approached the quality, substantive coverage, and sheer effectiveness of the EMFI."

STEM teaching and assessment methods that really work — K-12 to grad school

Math with ATTITUDE

"It is well known that the U.S. needs to improve K-12 education. I can't think of a better way to do this than to show students and teachers what mathematics, science and engineering are really about," said Barbara Moskal, a professor in the Department of Mathematical and Computer Sciences, who believes the subjects are really about fun.

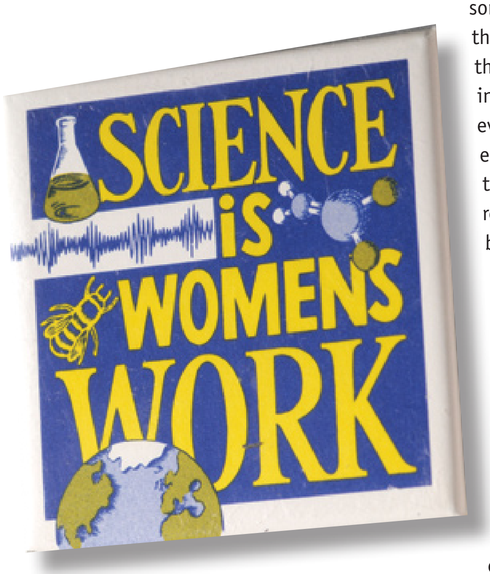
Moskal was an instructional aid for teachers in lower grades before she finished high school, and started teaching at a Sylvan Learning Center in Pittsburgh while completing her bachelor's degree. Today she primarily teaches engineering statistics. Moskal's mission extends beyond higher education to making subjects such as engineering, mathematics, science and technology accessible to schoolchildren and their teachers.

Her research measures student knowledge, beliefs and attitudes in science, technology, engineering and mathematics (STEM) — subjects in which U.S. students' test scores consistently lag behind those of many of their foreign counterparts. STEM is the focus of President Barack Obama's expansion of the "Educate to Innovate" campaign, designed to lift American students to the top of the pack in science and mathematics achievement over the next decade.

Barbara Moskal

Moskal directs the Mines Center for Assessment of Science, Technology, Engineering and Mathematics (CA-STEM), which aims to improve the evaluation methods of STEM education from K-12 to graduate levels. CA-STEM brings together research experts to evaluate educational projects and provide assessment and evaluation training for students and researchers. By measuring changes that occur as a result of educational interventions, Moskal says her team can help educators concentrate resources on educational activities that work.

"I am perpetually amazed at Barb's ability to do all of the things she does and at her passion for her work. I am also very pleased at the level of scientific rigor that goes into her planning and implementing of K-12 teacher development and outreach," said Barbara Olds, a professor in the Division of Liberal Arts and International Studies and director of the Trefny Institute for Educational Innovation, to which Moskal's CA-STEM Center reports. "It is our goal, nearing reality, to have a seamless pipeline from some of the school districts that Barb serves through her research from kindergarten through 12th grade, to community college in some cases, and then on to Mines. But even for students whose careers do not end up in math, science or engineering, the education in those fields they have received from Barb's group will make them better informed citizens."



Moskal and her team provide classroom support, develop curricular materials and analyze student data. Her team, drawn from the fields of mathematics, computer science, engineering and physics, is comprised of 17 graduate students, two undergraduate work-study students and an undergraduate student researcher. They support field-based scientists and engineers to make their K-12 outreach and educational activities more effective. Active researchers can generate tangible excitement in students that surpasses dry textbook-based lessons while hands-on activities turn abstract concepts into concrete, understandable ideas. For example, in one project, students construct bottle rockets from soft drink bottles to explore the effects of pressure.

"Mines scientists and engineers are excited about their work. This is something that we need to share with the broader learning community," Moskal said.

One way that excitement is shared is through the Renewable Energy Materials Research Science and Engineering Center (REMRSEC) at Mines. As the K-12 outreach coordinator, Moskal organizes summer workshops for schoolteachers that are taught by scientists and engineers. This year Mines' NSF GK-12 Learning Partnership Program was recognized by the American Society for Engineering Education as a best practice in middle school outreach. In 2008, this successful middle school program was updated and transported to the elementary level through the generous support of Stephen D. Bechtel, Jr. In combination, these programs support the K-12 pipeline, enhancing the next generation's understanding and interests in STEM.

According to REMRSEC Director and Physics Professor Craig Taylor, the REMRSEC proposal to the NSF was greatly strengthened by the center's ability to couple with Moskal's nationally known and respected K-12 outreach efforts.

"Her innovative approach to improving teaching and learning at the K-12 level is not only unique but also very effective. Our renewable energy center is privileged to have Barb as a major contributor to our educational outreach efforts," Taylor said.

Mines' outreach soon will extend to Colorado's Western Slope some 250 miles away from campus. With funding provided by the ExxonMobil Corporation, Meeker County Schools will connect to the program via interactive video. Moskal is eager to test the program's effectiveness through this innovation, which she says could greatly advance her team's ability to impact other K-12 schools across the nation.

Moskal's graduate students have developed new avenues of investigation as well, in local and international efforts. Leanne Miller developed and implemented Tech Camp 101, a U.S. computer science camp that draws 100 underprivileged middle school students every summer. David Pesek took curriculum development and assessment efforts to Kabul, Afghanistan; and Jason Dinh, Alex Probst and Nina Vollmer have worked on the group's efforts in Uganda, Africa.

"I love this component of my work — watching students develop their ideas and emerge as scholars," Moskal said.

Few K-12 educational researchers make the connection to higher education that Moskal does. "Most educational researchers apply their measurement skills to the evaluation of traditional K-12 educational curricula; my research team examines the feasibility of designing K-12 education using the science that is discovered today," she said.

Moskal is a respected voice in her field and a frequently requested speaker at educational conferences in Washington, D.C.

"There is so much more work to be done in STEM education and we want to be there to do it. The challenge is keeping up," Moskal said.

But Moskal isn't content to just keep up. Within five years she plans to include high schools in her research efforts, and in a decade she wants Mines to be a national leader in STEM education and evaluation research.

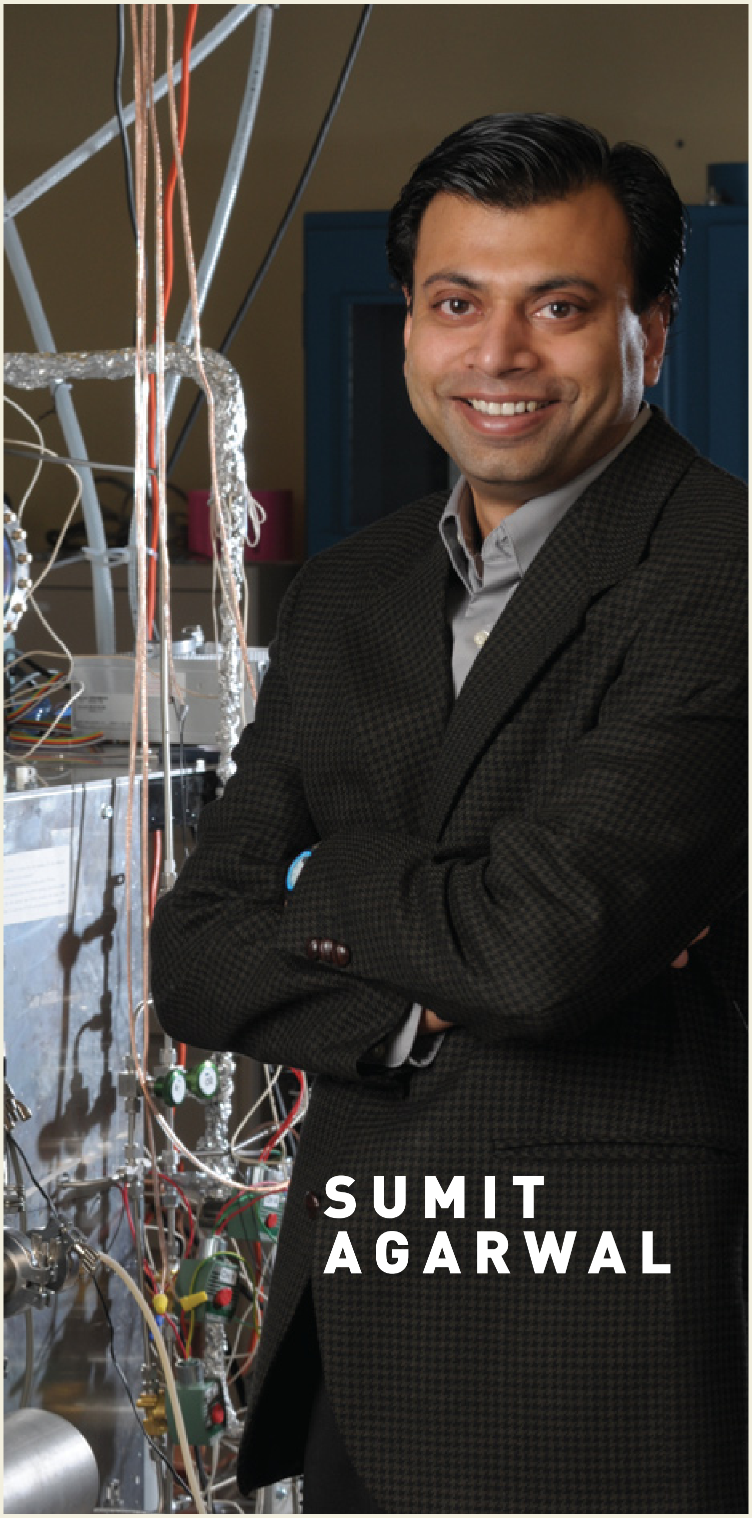
"Our vision is to change how mathematics, science and engineering are taught, measured and perceived. The inclusion of new scientific developments, at all levels, is key to reaching this vision," Moskal said.

Mines teacher-scholars garner NSF awards

Early SUCCESS

The National Science Foundation Faculty Early Career Development Program awards are the agency's most prestigious awards in support of junior faculty, honoring those who exemplify the role of teacher-scholars through outstanding research, excellent education and the integration of education and research within the context of the mission of their organizations. Career proposals are peer-reviewed and recommended for funding based on their intellectual merit and on the potential broader impacts of the proposed activities.

Kip Findley, assistant professor of metallurgical and materials engineering, was awarded $605,000 for his project, "The Stability and Influence of Metastable Retained Austenite During Fatigue of Advanced Steel Alloys." The project will examine the effect of deformation-induced changes on fatigue properties of two important advanced steel alloy systems for the transportation and infrastructure industries. Outreach will be conducted through high school teacher participation in the research and learning modules for students in the Colorado Uplift Program.



Sumit Agarwal, assistant professor of chemical engineering, was awarded $404,700 for "Molecular Perspectives of Gas-Surface Reactions during Growth of Thin Film Nanostructures." The project aims to develop methods to precisely synthesize thin layers of insulators, metals and polymers at the atomic or molecular level. The research has applications in microelectronics, optoelectronics and photovoltaics.

Anthony Petrella, assistant professor of engineering and director of Mines' Computational Biomechanics Group, is working on a human lumbar spine project that would predict how treatments might work on a large population of patients. The project, "Computational Modeling for Population-Based Evaluation of Spine Procedures," was awarded $400,000. Petrella will build a computer model to simulate the complex biomechanics of the lumbar region that ultimately could improve preclinical testing for low back pain treatments such as medical devices and surgical interventions.

Cristian Ciobanu, assistant professor of engineering, was awarded $400,000 for his project titled "Structural Helicity in Ultra-thin Alloy Nanowires." Ciobanu's project investigates how nanowires composed of various alloys can perform mechanically and electrically. The research could lead to improvements in nanoscale devices.


ANTHONY
PETRELLA


CRISTIAN
CIOBANU

Interdisciplinary research: It's all about connections

Faculty from multiple disciplines come together at the Center for Automation, Robotics and Distributed Intelligence (CARDI) to pursue complex projects. Sharing expertise in specialized areas, they learn the languages of the other disciplines and eventually find a common language.

Mines Division of Engineering faculty, along with professors from the Mathematical and Computer Sciences Department, conduct collaborative research through the center. Led by director Kevin Moore, the G.A. Dobelman Distinguished Chair and a professor of engineering, and by co-director Tracy Camp, a professor of computer science, CARDI currently has 21 faculty members representing five disciplines.

CARDI projects span a diverse spectrum, from research involving computer coding and augmented reality to sensors and robotics. For example, the MineSENTRY project involves autonomous mobile robots that act as radio relays combined with a network of sensors in an underground mine. The system is intended to improve safety during mining operations and facilitate search and rescue efforts during an emergency. Another CARDI research project is focused on improving efficiency in large buildings by using distributed sensors that monitor occupancy patterns and energy use and make adjustments to heating, ventilation and air conditioning controls.

"I find it exciting to work outside the box of my own discipline. CARDI is in a sense the epitome of what I like about Mines," said Moore. "As an electrical engineering professor at Mines, I have worked on research related to fuels cells, intelligent road construction, mining, robot arms and wireless sensor networks."

Under the CARDI umbrella there are several research groups carrying out projects in computer science, energy distribution, geosystems and robotics. Specific research groups include "Toilers," "ReDUCE," and "SmartGeo."

Camp directs the Toilers, a research group that focuses on wireless ad hoc networks, which are defined by a lack of a fixed infrastructure such as those created on an "as needed" basis. For example, in an environmental disaster, the current wireless networking infrastructure may be demolished. Members of Toilers have invented, implemented and compared several diverse network protocols, including protocols for both mobile networks and wireless sensor networks. Applications of ad hoc networks include environmental and structural monitoring, search and rescue, and tracking.

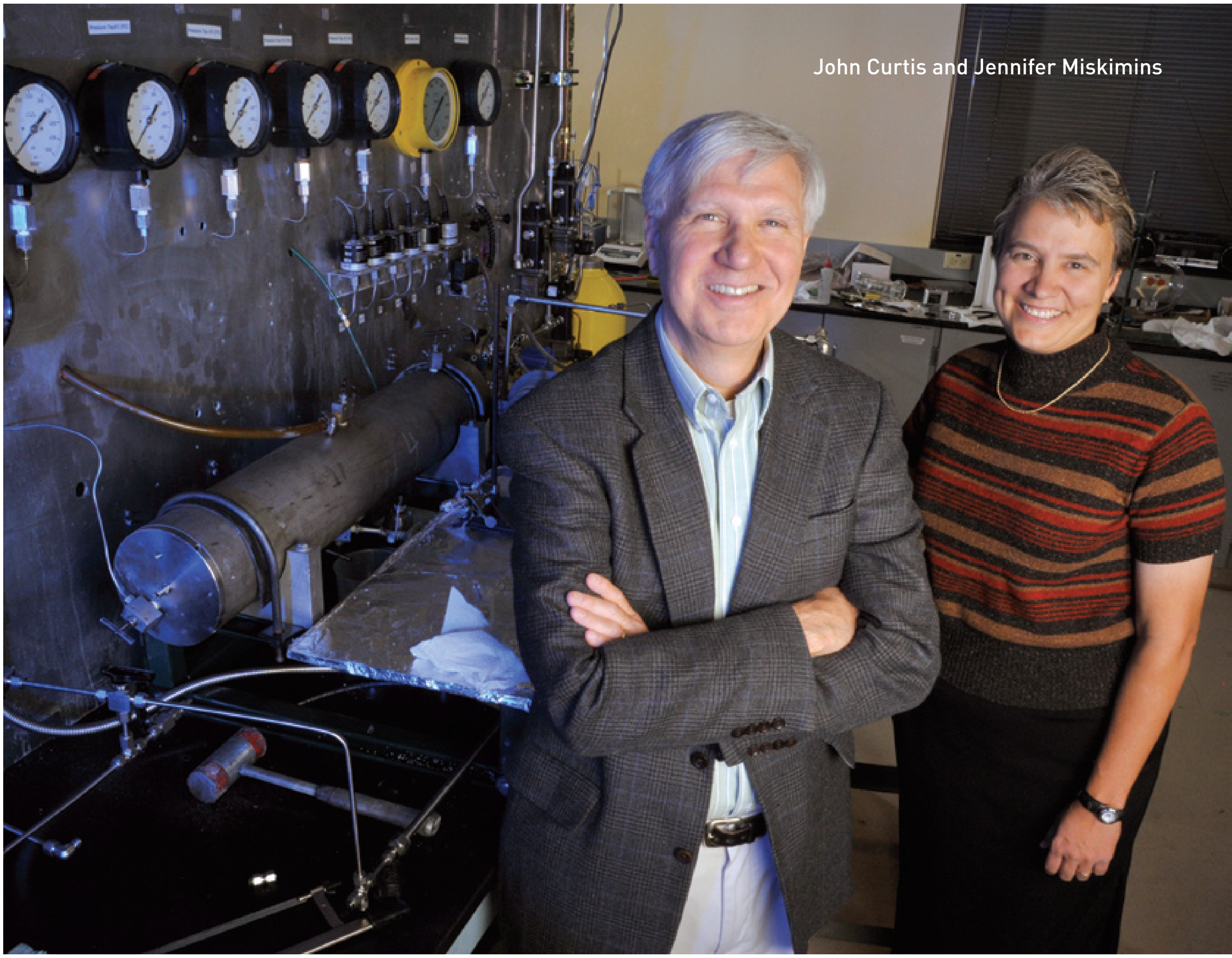
ReDUCE investigates methods to optimize the distribution, storage and utilization of energy through the application of sensor networks, intelligent control systems, advanced power electronics and the integration of simulation, optimization and design. The National Science Foundation (NSF) sponsors a major project seeking to push the state-of-the-art in simulation, optimization and control of energy flows in buildings to achieve better energy efficiency.

Another project, led by Tyrone Vincent, is part of an effort by ITN Energy Systems based in Littleton, Colo., to develop a low-cost manufacturing process for electrochromic film for windows. Electrochromic windows can darken or lighten in response to an electric signal so they have the potential to reduce energy costs by increasing or decreasing the amount of radiant energy entering a building. The current high cost of manufacturing puts the windows out of reach for many builders, and it is hoped that the ReDUCE research will help develop control systems that minimize manufacturing costs.

SmartGeo is part of a larger campus-wide NSF educational grant — the Integrative Graduate Education and Research Traineeship (IGERT). SmartGeo research efforts focus on advancing intelligent geoconstruction, intelligent earth dams and levees, and remediation of contaminated soil and water. Intelligent geosystems enable engineered and natural earth structures and environments to sense their environment and adapt to improve performance. Its work has applications for tunneling, deep drilling, seabed floor construction monitoring and more. Mike Mooney, a professor in the integrated civil, electrical and mechanical engineering division, directs SmartGeo along with co-director Camp. It's a perfect example of CARDI's interdisciplinary approach because not only does SmartGeo require expertise in soil science and hydrology, but also in wireless computer network routing protocols and robotics.

In addition, CARDI researchers carry out other projects including research in augmented reality, a technology for displaying computer graphics overlaid upon the real world. The development of an autonomous lawnmower is one possible outcome of their efforts.

From left, Mines students Jesse Hulbert and Chris Meehan work on a robotics project.



John Curtis and Jennifer Miskimins

Unconventional natural gas research: A concentrated effort

The Unconventional Natural Gas Institute (UNGI) centralizes all the multidisciplinary research in unconventional natural gas at Mines.

"We view it as 'one-stop shopping' for all things in unconventional gas. UNGI doesn't interfere with or seek control of this research. All of the individual principal investigators are doing fine and don't need that. UNGI just helps to spotlight this work and is a pivot transfer point for the technology," said Jennifer Miskimins, UNGI co-director and associate professor in the Petroleum Engineering Department.

Miskimins is also director of the Fracturing, Acidizing, Stimulation Technology (FAST) Consortium. Her research interests include stimulations, hydraulic fracturing, well completions, rock mechanics, unconventional reservoirs and multidisciplinary research. She said UNGI provides unbiased information regarding the development of unconventional resources and the impacts of technologies used in producing them.

Natural gas is clean burning so it helps minimize greenhouse gas emissions, and it's in great supply in the United States. Based on work by Mines researchers, the Potential Gas Committee reported estimates of gas resources increasing from 1,300 trillion cubic feet in 2006 to 1,800 trillion cubic feet in 2008 — with the majority of the increase from unconventional resources such as shale gas. Natural gas is considered the "bridge fuel" between other forms of fossil fuels and renewable energy technologies — making it a particularly valuable resource today. Unconventional gas systems are anticipated to be important energy contributors for a long time, both in the United States and internationally, prompting the UNGI co-directors to describe it as a "right place, right time" initiative.

John Curtis, a professor in the Geology and Geological Engineering Department, is UNGI's other co-director and he also directs the Potential Gas Agency. His research interests include natural gas resource assessment, petroleum geochemistry and petroleum exploration and development. Curtis said UNGI, which was started in August 2009, grew out of Mines' vast experience in unconventional gas.

"To our knowledge, nowhere else in the world is there a research institute that brings together under one roof the amount of multidisciplinary expertise in unconventional natural gas that UNGI does. Many faculty at Mines were working on unconventional gas before it was even formally named 'unconventional,'" Curtis said.

UNGI has consolidated expertise from at least seven departments including Petroleum Engineering, Geology and Geological Engineering, Geophysical Engineering, Environmental Science and Engineering, Engineering, Chemistry and Geochemistry, and Chemical Engineering. At this point the new entity is focused only on the research conducted at Mines, but in time it will seek collaborations with other research entities to strengthen the overall initiative.

In the immediate future, UNGI will focus on unconventional resources, such as tight gas sands and shale gas systems. Its long-term projects include production from hydrates. Across all systems, research will be conducted on the environmental impacts of these types of developments.

Mines students are involved in UNGI's work both through academic departments and the dozen research groups affiliated with the institute: Center for Earth Materials, Mechanics and Characterization; Center for Hydrates Research; Potential Gas Agency; Center for Petrophysics; Center for Rock Abuse; Center for Wave Phenomena; DHI/Fluids Consortium; Golden Energy Computing Organization; Fracturing, Acidizing, Stimulation Technology Consortium; Marathon Center of Excellence for Reservoir Studies; Petroleum Exploration and Production Center; and the Reservoir Characterization Project.

"We are currently soliciting membership in the institute. These members will have a seat on the institute's board of directors and will help to determine future directions of research at Mines in the area of unconventional gas," said Miskimins, who noted that members of the natural gas industry are currently supporting the institute.

Jeremy Boak

Powerhouse for energy research

Colorado School of Mines has a long history of energy-related research, from the early days of mining to today's most promising new sources of energy.

The university is home to a number of institutes and centers devoted to various aspects of energy, including the Colorado Energy Research Institute (CERI), which works to identify new energy research and development opportunities by increasing cooperation and communication among government, industry, universities and the public. The Colorado Legislature established CERI in 2004. Dag Nummedal serves as executive director with the assistance of George William "Jerry" Sherk as managing director.

"The scope of coordination and communication needed for CERI to be successful is broader than most people appreciate," said Sherk. "It reflects the conclusions of the recent *Body of Knowledge* report issued by the American Society of Civil Engineers. As future engineers need to understand the policies, statutes and regulations applicable to their profession, our research approach is equally multidisciplinary. CERI has been very successful in coordinating both interdisciplinary and interinstitutional research efforts."

Sherk reflects this multidisciplinary approach — he holds a doctorate in environmental and energy management from the School of Engineering and Applied Science at George Washington University and a law degree from the University of Denver.

One of the newest components of CERI is the Carbon Management Center (CMC). It's also a center of the Colorado Renewable Energy Collaboratory, and is operated in partnership with the University of Colorado, Colorado State University and the National Renewable Energy Laboratory. The Center for Oil Shale Technology and Research (COSTAR) was established at Mines in 2008 to integrate efforts in scientific and engineering research related to development and production of hydrocarbons from oil shale.

"Altogether, the three entities make Mines a powerhouse for energy-related research and development. With strong ties to industry and government, they have the potential to lead the way to reducing carbon dioxide, tapping into vast oil reserves to help bridge the gap while renewable energies are being developed, and sharing innovative solutions to bring about large-scale changes more quickly," said Nummedal.

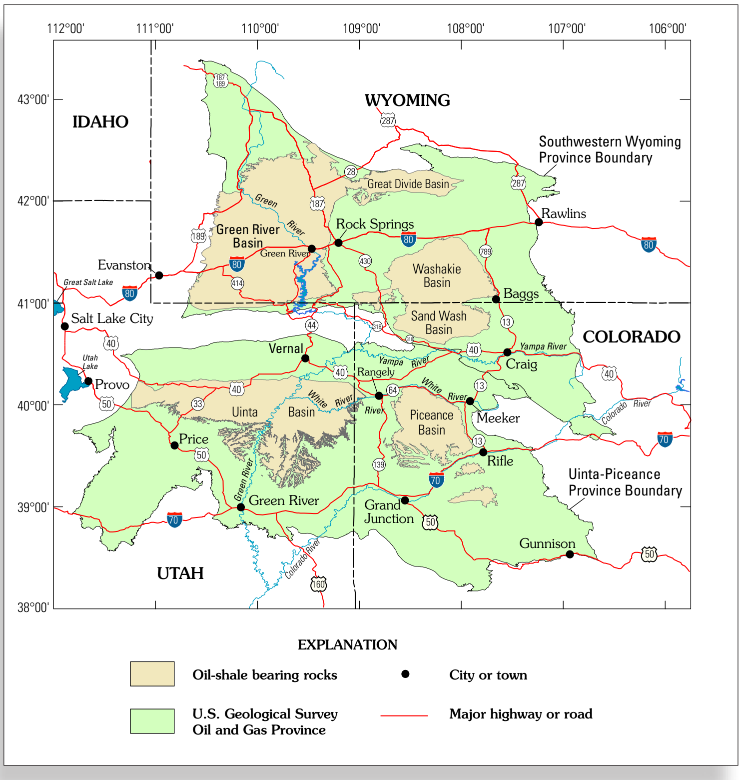
Nummedal noted that carbon sequestration, the focus for the CMC, is emerging as the leading technology to reduce carbon dioxide in the atmosphere. In partnership with other Colorado universities, CERI conducts research in terrestrial sequestration and performs legal and regulatory analysis. The core of the CMC portfolio is its basic research addressing three critical geoscience issues: geomechanical effects of pumping a new fluid (supercritical carbon dioxide) into underground storage reservoirs; geomicrobiological impacts of carbon dioxide that is pumped underground; and mineral dissolution and precipitation along the flow paths of the injected carbon dioxide.

Marte Gutierrez, the James R. Paden Distinguished Professor of Civil Engineering in Mines' Division of Engineering, is the principal investigator on the geomechanics research, which includes advanced laboratory and numerical modeling of how rock fractures form and potentially heal inside the volume of rocks where carbon dioxide is stored. Kevin Mandernack, a professor in the Department of Chemistry and Geochemistry, is investigating microbiological effects of carbon dioxide storage in collaboration with the U.S. Geological Survey (USGS). Environmental Science and Engineering Division Director John McCray and post-doctoral fellow Alexis Sitchler are investigating how minerals dissolve or precipitate in response to carbon dioxide injection. The two are applying a range of sophisticated technologies including scanning electron microscopy and neutron beam scattering experiments.

Researchers with the CMC are studying parts of the Denver sedimentary basin to determine its suitability for large-scale sequestration of carbon dioxide. There is growing industrial interest in this option, particularly if carbon dioxide sequestration could be combined with enhanced oil or gas recovery.

The CMC also was recently appointed as the U.S. coordinator for the new International Performance Assessment Centre For Geologic Storage of CO2 (IPAC-CO2). Funded by Shell and BP, IPAC will work in parallel with the Canadian Standards Association and the International Organization for Standardization to ensure that carbon sequestration around the world will be performed according to the best practices and highest technical, environmental, economic, legal and regulatory standards, regardless which country is the host for the underground carbon storage facility.

While the CMC focuses on carbon dioxide management, COSTAR is the only university-based research center in the U.S. focused solely on advancing understanding of the formation and properties of oil shale. Formed millions of years ago by silt, mud and organic debris deposits on lakebeds and sea bottoms, oil shale can be mined and processed. The end product is similar to oil pumped from conventional oil wells, but currently the extraction process is more expensive than conventional oil recovery.



U.S. Geological Survey

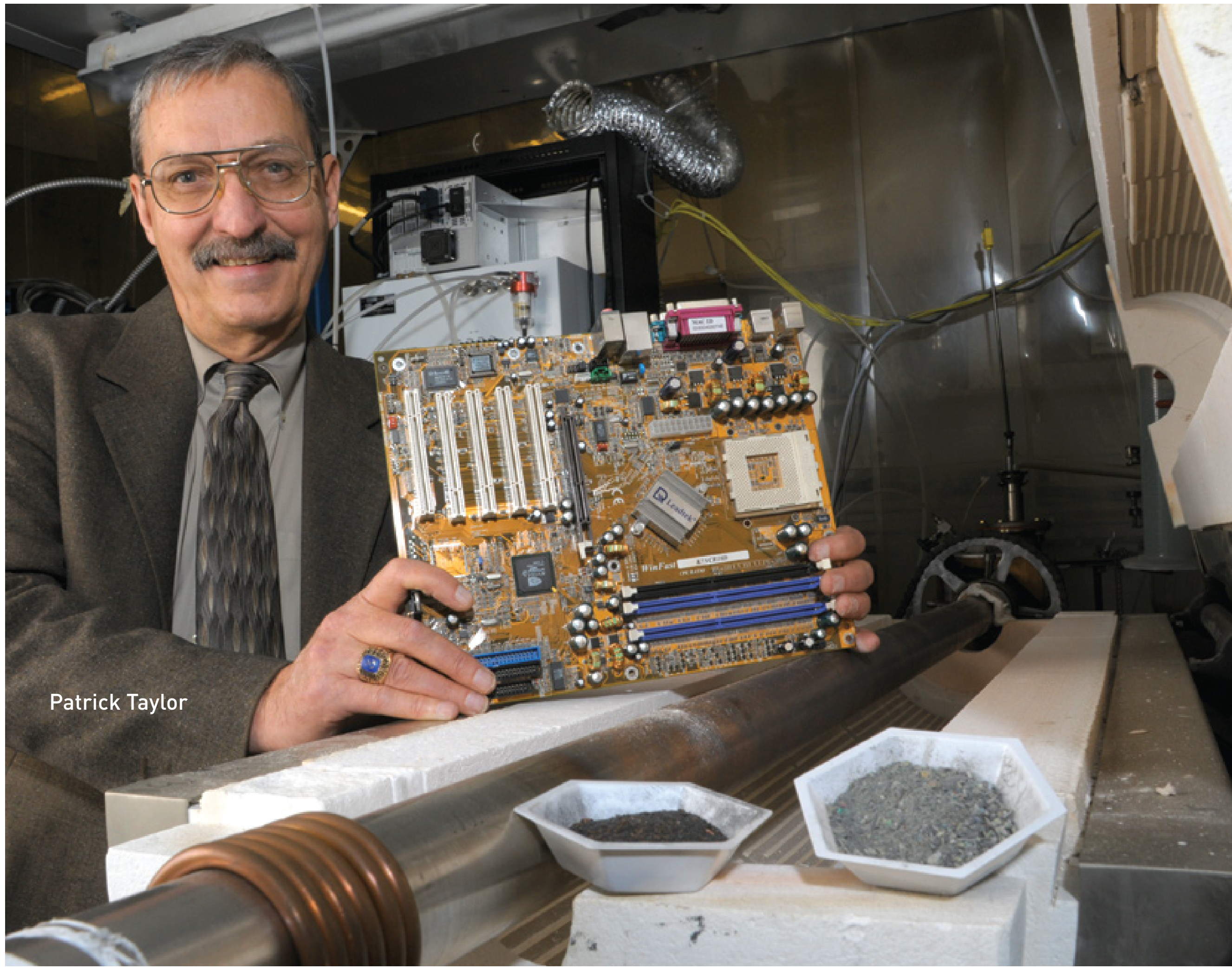
"Oil shale resources could potentially provide the world more than twice the amount of oil produced since production began in the 1800s," said Jeremy "Jerry" Boak, COSTAR director. "It is exciting to be involved at a time when actual production is very small, and the results of our research could be incorporated into the rapid growth of an industry that has been around for a long time."

The Green River Formation in Colorado, Utah and Wyoming holds the world's largest deposits of oil shale. An estimated 800 billion barrels of oil are recoverable from the oil shale in the Green River formation — an amount three times greater than the proven oil reserves in Saudi Arabia. Boak said such resources could significantly affect the future of oil production worldwide and could provide clear energy security benefits for Colorado and the United States, but he cautioned that there are significant challenges to achieve that potential.

COSTAR's two major research objectives are to help develop oil shale resources to enhance global energy supplies and to minimize the environmental consequences of developing oil shale. It engages research affiliates at the University of Wisconsin and Binghamton University and benefits from the nearby presence of the USGS.

The Department of Energy's National Energy Technology Laboratory provides significant funding for the CMC. The state of Colorado is providing some matching funds through the Collaboratory. COSTAR is funded by a consortium of three major oil companies: Total, Shell and ExxonMobil. Other oil shale projects are funded through the National Energy Technology Laboratory and through a contract with the government of Thailand.

"We have generally focused on the oil shale in our backyard, but we're convinced that the integrated geologic framework we are building will lead to concepts about oil shale formation that will have global applicability," said Boak.



Patrick Taylor

Institute fills gaps in materials resource recovery

The Kroll Institute for Extractive Metallurgy (KIEM) provides research expertise and well-trained engineers to industry, as well as providing research and educational opportunities to students in the areas of minerals processing, extractive metallurgy, chemical processing of materials, recycling and waste treatment and minimization.

"KIEM is one of the few existing centers in the world available and ready to fill the increasing gap in technology, personnel and research in rapidly expanding areas of strategic and critical materials resource recovery," said KIEM Director Patrick Taylor, the George S. Ansell Distinguished Professor of Chemical Metallurgy and a professor in the George S. Ansell Department of Metallurgical and Materials Engineering.

Taylor said the research and trained professionals that KIEM provides have become increasingly important as developing countries expand their economies and require more of the earth's resources. Because much of the technology required to expand energy utilization into alternative sources requires materials from the earth that are becoming more costly and scarce, resource recovery issues are critical to the United States.

It's one of the few centers of excellence in extractive metallurgy, mineral processing, recycling technology and waste minimization in the country, and its faculty consists of internationally recognized experts in these fields. Research and graduates from KIEM have been leaders in the field since the institute's inception.

KIEM was established at Colorado School of Mines in 1974 using a bequest from William J. Kroll. Kroll was a world-renowned extractive metallurgist who was best known for his inventions of processes for the production of titanium and zirconium. Industrial sponsors support the institute's in-depth, practical academic research. Looking forward, KIEM will continue to develop research programs with industry relating to the mineral processing and extractive metallurgy of complex ores, water reuse issues, recycling and waste minimization and recovery of strategic and critical materials.

"The research is directed at important resource recovery issues and can play a big role in decreasing our country's dependence on foreign sources. In addition, developing economic and environmentally benign technologies can help improve the overall economy of the country," said Taylor.

Faculty members in the Kroll Institute teach, conduct research and perform service in all aspects of mineral and metal resource recovery.

The institute's faculty have garnered numerous recent awards. D. Erik Spiller was awarded SME's Richards Award; Corby Anderson was awarded the Wadsworth Award from SME and was named Fellow of the Institute of Chemical Engineers. Brajendra Mishra, a Fellow of ASM, was the past president of TMS, is president-elect of the American Institute for Mining, Metallurgical and Petroleum Engineers and has received the TMS Distinguished Service Award. Taylor earned the Distinguished Service Award and the Distinguished Lecturer Award from TMS; the Distinguished Member Award and the Wadsworth Award from SME; and Fellow Award from ASM.

Kroll Institute undergraduate and graduate students with a background in minerals and metals resource recovery are heavily recruited by a variety of industries, including the major mining companies. KIEM also supports Mines' educational and research mission in nuclear engineering, mining engineering and energy and materials, as these areas of specialization require understanding of physical and chemical processing related to minerals and metals recovery and refining.

In February, KIEM and the Worcester Polytechnic Institute (WPI) in Worcester, Mass., established the Center for Resource Recovery and Recycling, known as CR3. This industry-university research consortium is the nation's first research center dedicated to developing new technologies for maximizing the recovery and recycling of metals used in manufactured products and structures. A five-year, $400,000 award from the National Science Foundation (NSF) will fund the cost of establishing the center (to be located at both institutions) and recruiting corporate members. Industry membership dues will augment the NSF funds. Projects will be selected by the industry members and will be directed toward solving important recycling physicochemical processing issues.

"Conserving and preserving materials, energy and resources are the needs of the day for societal sustainability," said Mishra, the new center's associate director. "The generations to come require us to take on this responsibility."

KIEM-CR3 will focus on metals used in functional applications, including high-value and rare earth metals used in computers, electronics and photovoltaics. In addition to conducting research, CR3 will develop materials recycling and recovery curricula to prepare a workforce ready to meet the challenge of promoting sustainability in the materials industries.

Judith Gómez works on a new electrolysis deposition method to produce high purity boron.

Jacob Hohn develops a process flow sheet for the recovery of valuable metals and energy from pyrolyzed electronic scrap.

Kimberly Connor works on pressure oxidation of complex copper concentrates.

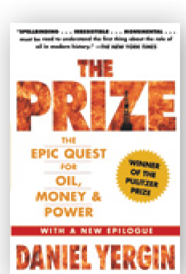
Tara Davis performs several leaching column tests for gold ores.

Joshua Amante Montenegro works on upgrading a Colombian iron ore.

A MESSAGE FROM

Daniel Yergin

Chairman of IHS Cambridge Energy Research Associates



When it came time for me to sit down and prepare the new updated edition of *The Prize: the Epic Quest for Oil, Money, and Power*, I knew that I had to think in terms of themes. Big themes. What had changed since the first edition? And, as I reflected, it was clear to me that one of the most important changes of all is the new, more intense emphasis on innovation in energy. That is true, whether in terms of the growing role of alternatives and renewables or in terms of the conventional energy – oil, natural gas, coal – that provides 83 percent of America's total energy.

But innovation does not exist in a vacuum. It rests upon a foundation — research — whether on near-term issues or at the frontiers of thought. And that research imperative is central to the mission of Colorado School of Mines and its role in the world, both as an educational and as a research institution.

It was deeply meaningful for me to receive an honorary degree from Mines in 2008. In my address, I talked about how the wider public and policy worlds tended to underestimate the importance of technological progress in energy. To the graduating students on May 9, 2008, on Kafadar Commons, I said: "There is a critical need for basic research for problem solving, for innovation, for the application of science and engineering that you've learned in the classrooms here at Mines — all of this to gain a better understanding of the Earth and its resources, and how to develop them with sound environmental stewardship."

When one looks at the range of concerns — security and cost, environment and climate, growing energy demand from the emerging market nations — it is even more true today. And thus the emphasis on innovation and technology has increased, along with the support, which means that the opportunity is expanding for Mines to contribute across the energy spectrum.

That is why I am particularly pleased — in addition to being a proud degree recipient from Mines — to contribute to this issue, which communicates the wide range of research at Mines to the larger community of alumni and friends. This issue highlights the work, alerts us to the potential, and underlines the commitment of Mines to meeting its mission.

An institution with the capabilities and talents of Mines can make a great contribution. But there are three obvious requirements. The first is to have the talent, and that Mines certainly does. The second is time. The research endeavors described here will take patience and years to unfold. The pace is not predictable; otherwise, it would not be research.

The third need is financial. Because of the increased emphasis on innovation, more money is available. But not all of it will go to academic research by any means. The venture capital community has become an important player in the energy world, but its time horizon is shorter; it is looking for discernible exits and is not interested in, to borrow from its own language, "science experiments." Thus, the consistent commitment to research at an institution like Mines requires support from committed alumni, from the private sector, and from public resources.

A few years ago, The Gathering Storm study — led by Norman Augustine, who occupied this space two years ago — focused on the risks arising from the underfunding of research and development. The national and global interest — and Mines is a global institution — are not served by that underfunding. It is not constructive for a talented faculty to spend an inordinate amount of its time filling out applications and competing for too-limited resources.

Funding is being increased for energy research, and that is to be applauded and supported. But, over the years, we have seen how cycles of R&D support go up and down with the political currents. To ensure that the focus on innovation delivers on its promise requires a continuing commitment to long-term funding. That is needed to ensure that Mines and similar institutions are able to make the significant contributions of which they are capable. To ensure this happens at Mines requires, on the one hand, the strong support of the school's alumni and, on the other, enlightened decisions at the state and federal level.

I'm convinced that with the kind of commitment represented here, properly supported over the long term, we will see results that will help meet the world's energy needs and also, in a most positive way, surprise us. That is, after all, one of the lasting lessons of *The Prize*. And, as this issue demonstrates, that is what will happen when Mines applies its superb minds to the great issues of energy.

Daniel Yergin, who was awarded an honorary degree by Mines in 2008, received the Pulitzer Prize for *The Prize: the Epic Quest for Oil, Money, and Power*. The 2009 edition of his book includes a new epilogue.

Daniel Yergin is chairman of IHS Cambridge Energy Research Associates (IHS CERA). Its parent company IHS has recently begun a collaborative relationship with Mines in the area of environmental solutions, including IHS-supported research in carbon management and water remediation.

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