COLORADO SCHOOL OF MINES

ENERGY AND THE EARTH

RESEARCH 2011-12

IMPACT OF RESEARCH AT
COLORADO SCHOOL OF MINES

What is it about Mines? This small school nestled under the Rockies has worldwide impact. In fact, we are better known overseas than at home. Our alumni occupy positions of influence in universities, industries, national laboratories and governments around the world. Our impact rests on the premises that we believe and practice: a rigorous science and engineering education and sticking to our knitting in terms of focusing on an understanding of energy and the earth.

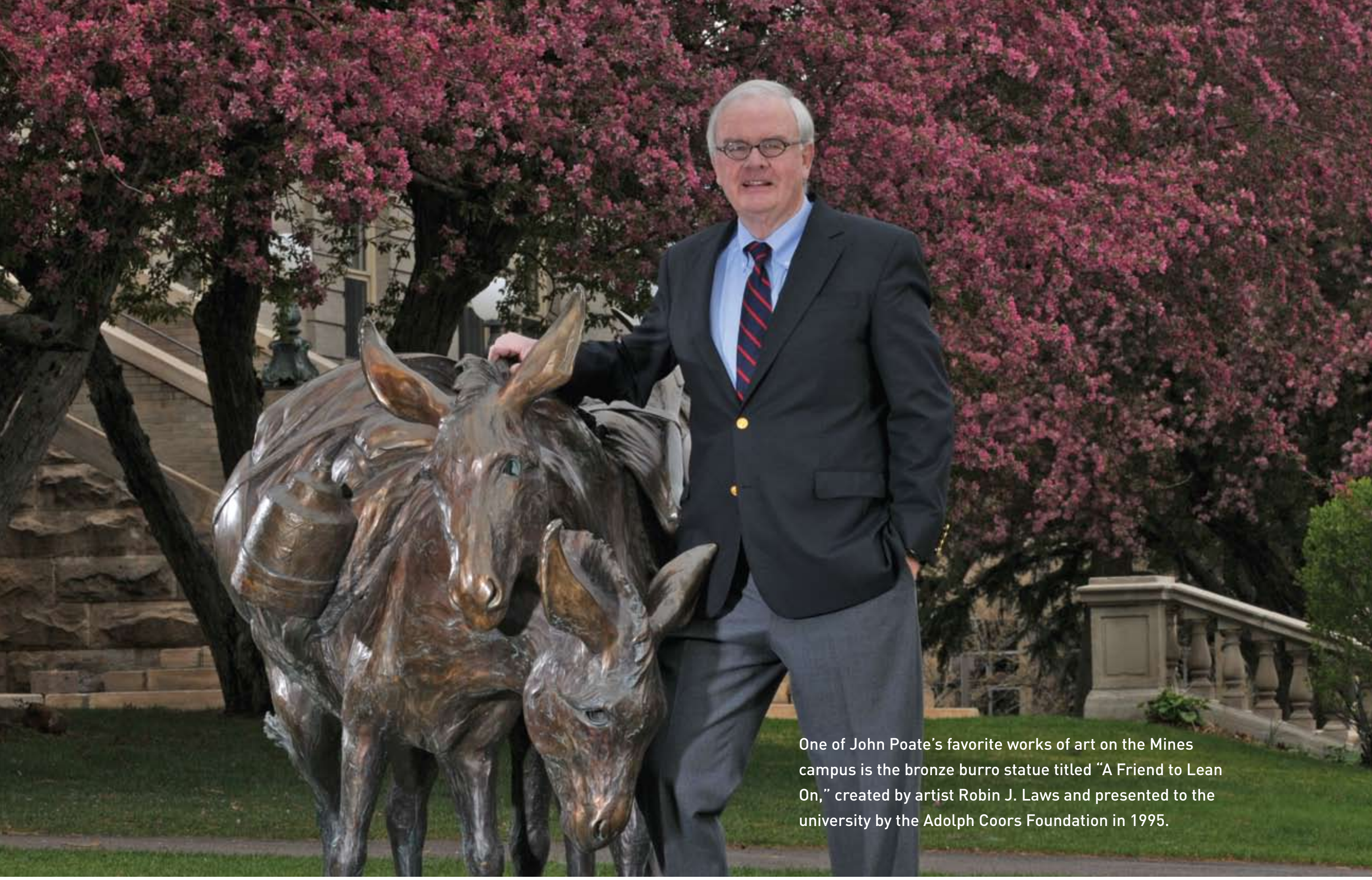
We have a storied history. We are older than the State of Colorado. Nathaniel Hill, a young professor from Brown, came to the territory in the 1860s and revolutionized the mining industry in the West by introducing technologies for smelting ores, primarily Au. He was one of our first trustees. Professor Arthur Lakes, in the 1870s, made the first discovery of the fossils of very large dinosaurs, which led to new theories about the fauna of that age and the evolutionary link between dinosaurs and modern animals. Professor Carl Heiland was brought to Mines in the 1920s to teach the first course in geophysical prospecting in the United States. This positioned us to be a leader in geophysical exploration and mapping. From the days of Nathaniel Hill, until now, we continue to lead in extractive and processing metallurgy in noble metals, actinides, rare earths and particularly ferrous alloys.

In the past 25 years we have brought together talented faculty to tackle grand challenges in the energy and environmental arena. Particularly noteworthy are the following:

- Our pioneering 3-D and 4-D characterization of oil and gas reservoirs have helped ensure adequate global supplies of energy.
- Our mineral and energy economics and economic geology studies have helped us understand the world's resources.
- Our methane hydrate research, a leading program among U.S. universities, was started to study the fundamental physics and chemistry, and evolved to solve pipeline plugging problems. It has now moved to the forefront of energy and environmental studies.
- Our photovoltaic research, which started with the founding of the National Renewable Energy Laboratory in Golden, continues to lead in new discoveries and manufacturing technologies.

More recently our research in the whole unconventional gas and oil domain has moved to the forefront of the national and international agenda. The thrust of our environmental research has been water. We lead not only in the study of water issues related to the extractive industries but also global sustainability. We have just been selected to receive a major National Science Foundation grant to study the urban water infrastructure in the West.

This current issue of Energy and the Earth highlights some of



One of John Poate's favorite works of art on the Mines campus is the bronze burro statue titled "A Friend to Lean On," created by artist Robin J. Laws and presented to the university by the Adolph Coors Foundation in 1995.

our most recent research activities, directed at solving complex problems facing society today. More and more our researchers are contacted by national and international media to provide expert insight on current, critical issues concerning energy and the earth. See the story "Mines in the News" on pages 25 to 27.

One of the key metrics to our impact and growth in research is the vitality of our graduate student population. We are attracting increasing numbers of the best and brightest. The recent Graduate Research Fair, featuring posters and oral presentations, covered our entire research portfolio. Organized entirely by our graduate students, this event is one of the largest in the country.

Particularly important for us and this research magazine are the interviews and comments from two eminent leaders in science and engineering, Marcia McNutt, a former faculty member in geophysics at MIT and our commencement speaker this year, is head of the United States Geological Survey. Craig Barrett, former faculty member in engineering at Stanford University, is the iconic CEO Emeritus of Intel Corporation. Both are passionate about expanding and encouraging science and math education.

As I said, we stick to our knitting at Mines, but the patterns and fabric keep changing and evolving. We are growing in the biosciences and bioengineering as these disciplines impact much of our mission. Engineers and scientists who are to lead in the future have to understand the broader worlds of the arts, social sciences and economics. These areas are flourishing at Mines. The research trajectory of the school is evolving rather rapidly.

As Arden Bement, former director of the National Science Foundation and a Mines graduate, recently said of Mines, "Right now, we've gained perhaps the highest level of recognition for excellence among top-tier universities that wouldn't have accepted the school as a peer a few years ago."

What are the biggest challenges to maintain our growth and impact? Along with the scientific and engineering challenges in the energy and environmental arenas, we are faced with economic challenges related to budgets at the state and federal levels. We must maintain progress in our academic and research mission, and knowing the caliber and talent of our faculty and students, I am confident of that progress. Mines will make significant advancements, continuing to have worldwide impact.

John Poate

Dr. John Poate
Vice President for Research and Technology Transfer

See John Poate's message to readers at researchmag.mines.edu or scan this code with your mobile device

COLORADO SCHOOL OF MINES
ENERGY AND THE EARTH

Contents

RESEARCH
2011-12

Features



COLORADO SCHOOL OF MINES

ENGINEERING THE WAY

Mines, a public research university devoted to engineering and applied science, has the highest admission standards of any public university in Colorado and among the highest of any public university in the nation. Since its founding in 1874, Mines has distinguished itself by developing educational and research programs that address the world's critical needs for energy, materials, water and the responsible stewardship of the earth.

MINES NUMBERS

5,093
Student body, undergraduates and graduates

36
Research centers on campus

$53.6 million
Research awards, fiscal year 2009-2010, with 40 percent funded by private industry and 60 percent by federal agencies

1
Society of Women Engineers, largest collegiate section in the nation

85, 88, 100
Percentages of bachelor's, master's and PhD graduates placed upon graduation in 2009-2010

$61,600
Median starting salary for BS graduates — the highest among all public universities in the nation according to Payscale.com.

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

Dr. John M. Poate
Colorado School of Mines
Vice President for Research and Technology Transfer

EDITORIAL

Karen Gilbert
Colorado School of Mines
Public Relations Director, Editor

David Tauchen
Colorado School of Mines
Public Relations Specialist, Editor

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

Marsha Williams
Colorado School of Mines
Public Relations, Senior Editor

ART DIRECTOR

Craig Korn
VeggieGraphics

PHOTOGRAPHY

Thomas Cooper
Lightbox Images

Additional Photography: Shutterstock.com

PRINTING

American Web
CPM Number #40065056

Colorado School of Mines
1500 Illinois Street
Golden, CO 80401

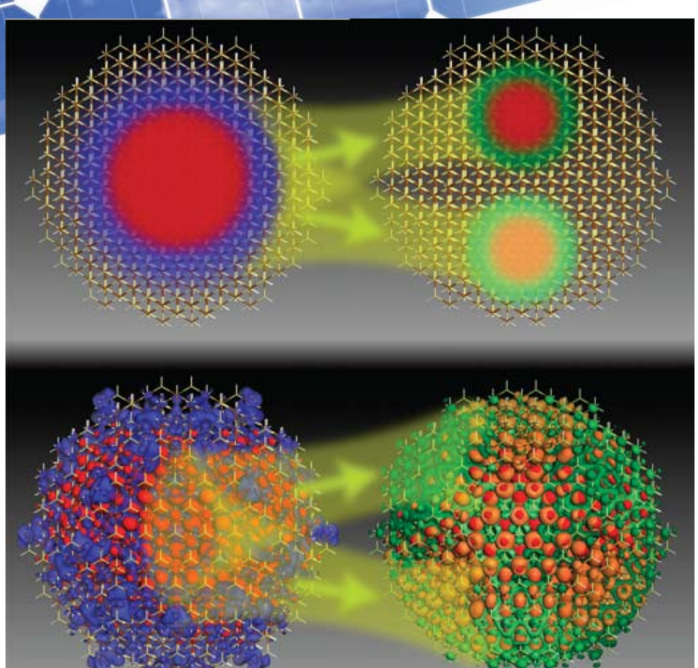
303-273-3000 or 800-446-9488

www.mines.edu/energyandtheearth
Online Extras: researchmag.mines.edu


SCHOOL OF MINES
1874
COLORADO


MUSEU

Solar Cells and Quantum Dots


Mark Lusk

Idealized images of an exciton (top left) and bi-exciton (top right) plotted as iso-surfaces of electron density on top of a 4.3 nm CdSe quantum dot. The bottom two images show an actual exciton and bi-exciton as predicted by our research.

Physics Professor Mark Lusk, leading a group of research colleagues at Mines, is working to improve the efficiency of solar cells.

The group's latest work describes how the size of light-absorbing particles — quantum dots —affects the particles' ability to transfer energy to electrons to generate electricity. Quantum dots are man-made atoms that confine electrons to a small space. They have atomic-like behavior that results in unusual electronic properties on a nanoscale. These unique properties may be particularly valuable in tailoring the way light interacts with matter.

The results were published in the April issue of the journal *ACS Nano*.

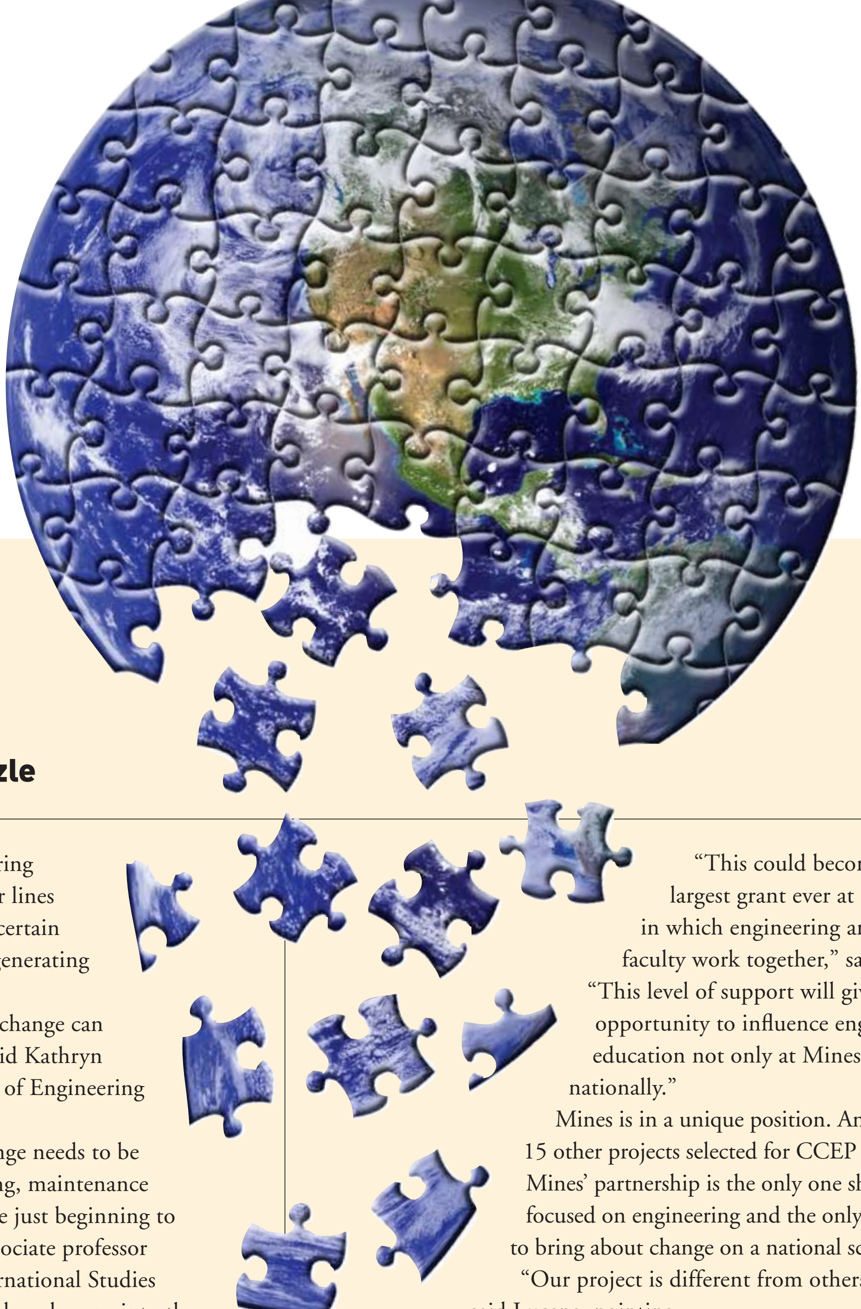
This advance provides evidence to support a controversial idea called multiple-exciton generation (MEG), which theorizes it is possible for an electron that has absorbed light energy (an exciton) to transfer that energy to more than one electron — resulting in more electricity from the same amount of absorbed light.

For this study, Lusk's team used a National Science Foundation (NSF)-supported high performance computer cluster to quantify the relationship between the rate of MEG and quantum dot size. They found each dot has a slice of the solar spectrum for which it is best suited to perform MEG and that smaller dots carry out MEG for their slice more efficiently than larger dots. This implies that solar cells made of quantum dots specifically tuned to the solar spectrum would be much more efficient than solar cells made of material that is not fabricated with quantum dots.

"We can now design nanostructured materials that generate more than one exciton from a single photon of light, putting to good use a large portion of the energy that would otherwise just heat up a solar cell," said Lusk.

The research team, which includes Alberto Franceschetti of the National Renewable Energy Laboratory, is part of the NSF-funded Renewable Energy Materials Research Science and Engineering Center at Mines. The center focuses on materials and innovations impacting renewable energy technologies — including new ways to enhance solar panel performance.

Watch the video at researchmag.mines.edu
or scan this code with your mobile device



Engineering Education and the Climate Change Puzzle

As the earth constantly changes, engineering systems must adapt: What happens to sewer lines near the coast as sea levels rise? How do uncertain weather patterns influence a wind turbine generating electricity?

"In some senses, engineering for climate change can be posed as engineering for uncertainty," said Kathryn Johnson, assistant professor in the Division of Engineering at Mines.

"Engineers are realizing that climate change needs to be a major consideration in the design, building, maintenance and operation of engineered systems and are just beginning to learn how to do this," said Juan Lucena, associate professor in the Department of Liberal Arts and International Studies (LAIS). "We want to learn how to transfer these lessons into the classroom."

The work is already underway. In fall 2010, the National Science Foundation (NSF) awarded a $1 million grant to a partnership that includes Colorado School of Mines, the National Academy of Engineering and four other institutions. It is called the Partnership for Education on Climate Change, Engineered Systems and Society.

Out of hundreds of submissions, NSF selected only 15 partnership awards for phase one of its Climate Change Education Partnership (CCEP) program. The money is used to host workshops across the nation, conduct extensive inventories of what is being done in engineering for climate change across the world, and develop an effective network of change agents in engineering education. In March 2012, Mines' partnership will submit a proposal to put these strategies to work in phase two of the CCEP grant, a $10 million dollar award over five years.

"This could become the largest grant ever at Mines in which engineering and LAIS faculty work together," said Lucena. "This level of support will give us the opportunity to influence engineering education not only at Mines but nationally."

Mines is in a unique position. Among the 15 other projects selected for CCEP phase one, Mines' partnership is the only one sharply focused on engineering and the only one seeking to bring about change on a national scale.

"Our project is different from others," said Lucena, pointing out it is the only one that includes a national network of both research universities (Arizona State University, Mines, Pennsylvania State University and University of Virginia) and non-university institutions with great influence on public education (Boston Museum of Science) and policymaking (National Academy of Engineering).

Furthermore, the project is explicitly committed to posing questions of social justice, sustainability, governance and public trust in ways that are often rare in the design and development of engineered systems.

"Engineers like myself tend to be very good at quantitative data but aren't always as strong in working with people," said Johnson. "Implementing new ideas on a large scale will require working with people of diverse backgrounds."

The NSF CCEP phase two grant awards will be announced in August 2012.

Building the Future for Petroleum Engineering and Energy Research

Construction is moving forward on Marquez Hall, a state-of-the-art facility for applied teaching and research in petroleum engineering. Mines broke ground on the new building in October. Its construction is possible through the support of Mines friends, corporate partners and alumni — kicked off by a $10-million matching gift from the Timothy and Bernadette Marquez Foundation.

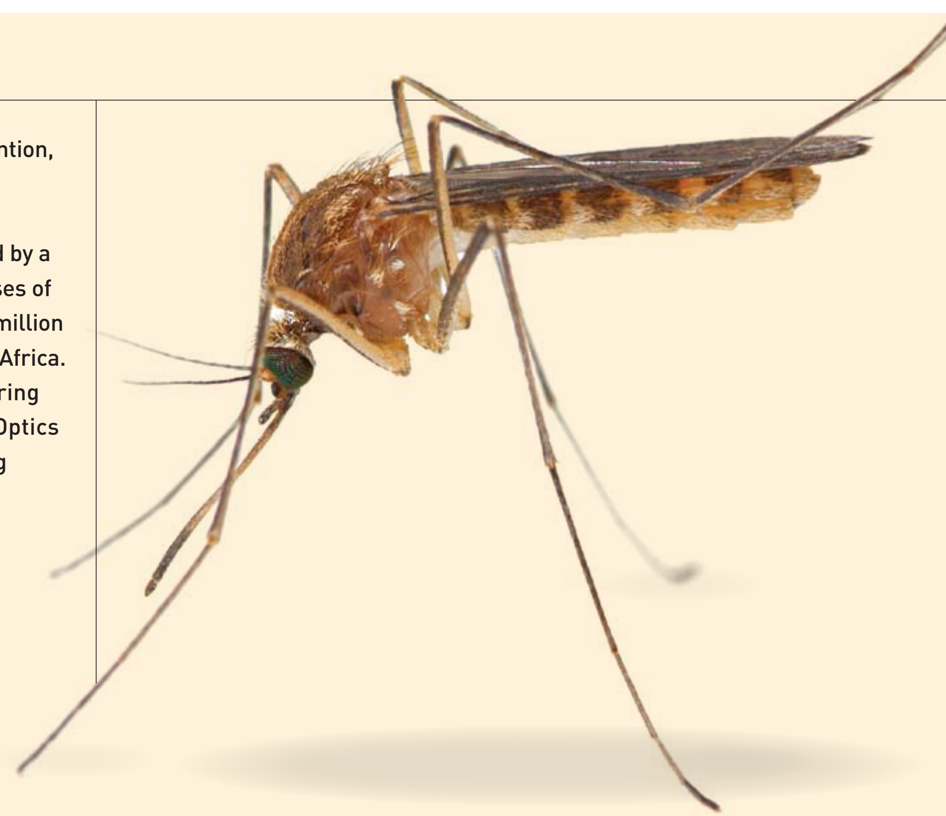
This soon-to-be campus landmark will provide 60,000 square feet of customized classrooms and research and teaching laboratories. Designed by the architectural firm Bohlin Cywinski and Jackson, known for designing the Pixar Studios headquarters in California and the Apple store on 5th Avenue in New York, the building will be LEED certified for sustainability and energy efficiency.

Research activity will focus on the challenge of increased worldwide energy demand and the need for innovative approaches to resource recovery.

Tools for Earlier Malaria Detection

According to the Centers for Disease Control and Prevention, malaria is the fifth-leading cause of death from infectious diseases worldwide. Half of the world's population lives in areas at risk of malaria, a mosquito-borne disease caused by a parasite. It is estimated that, in 2008, up to 311 million cases of malaria occurred worldwide, and 708,000 to more than 1 million people died, most of them young children in sub-Saharan Africa.

David Marr, professor, head of the Chemical Engineering Department and co-director of Mines' Microintegrated Optics for Advanced Bioimaging and Control Center, is working on a project that will aid biological researchers and those interested in developing analyses for detection of the disease. The effort, a collaboration with a research group at the National Institutes of Health (NIH), will develop tools to measure the change in red blood cell properties after infection with malaria.



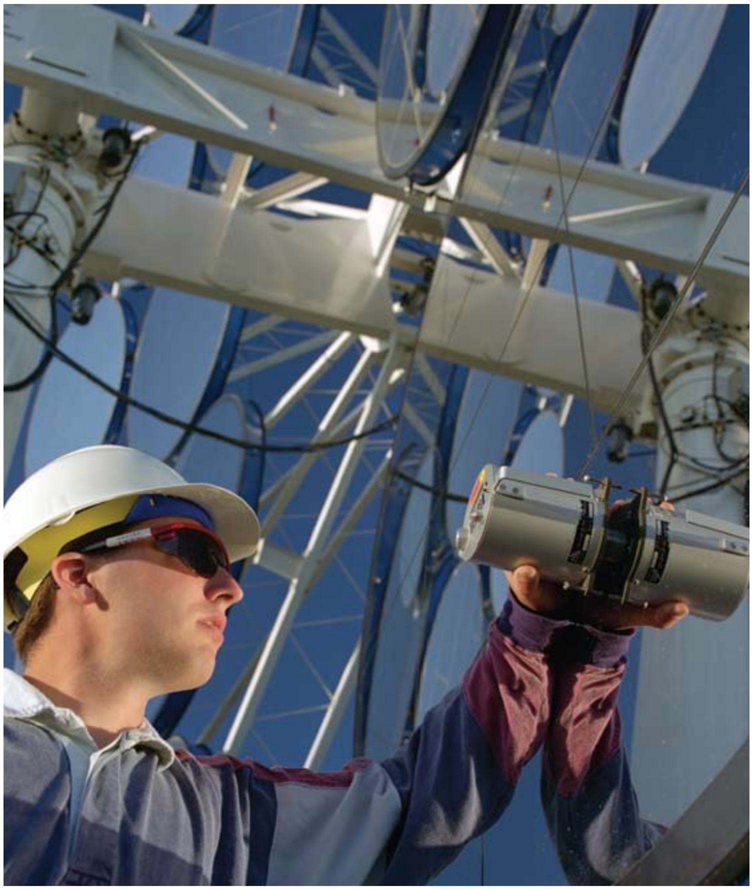
Transformative Materials for Efficient Energy Systems

Mines Professor Brajendra Mishra will lead a major study focused on materials that can transform developing energy technologies into clean, affordable and widespread options supporting new manufacturing opportunities and job creation.

For example, Mishra's team will focus on accelerating the development and manufacture of such innovations as cheaper solar cell materials that can convert more light into useful energy, and membrane technologies that can make carbon separation and capture processes more affordable and practical.

The study is one of five initiated by The Minerals, Metals, and Materials Society (TMS) on behalf of the U.S. Department of Energy Industrial Technologies Program. A report consolidating recommendations will be published in September 2011.

Mishra, professor and director of the Center for Resource Recovery & Recycling at Mines, will lead an Innovation Impact Team charged with developing strategic research plans for a select group of surface technologies. Special coatings and surfaces are routinely used to protect equipment and extend service life. However, emerging materials technologies will enable surfaces to play a key role in enhancing the functioning and efficiency of next-generation energy systems. Mishra will help set specific performance goals for these technologies and outline strategies that will enable these goals to be met within five to 10 years.



NREL

Marr's larger goal is to create biomedical devices that allow immediate screening and diagnosis of disease without the steps of sending samples, such as blood, off to the laboratory and awaiting results. Eventually, the research could lead to a significant decrease in cost and a great increase in accessibility for health care diagnostic devices.

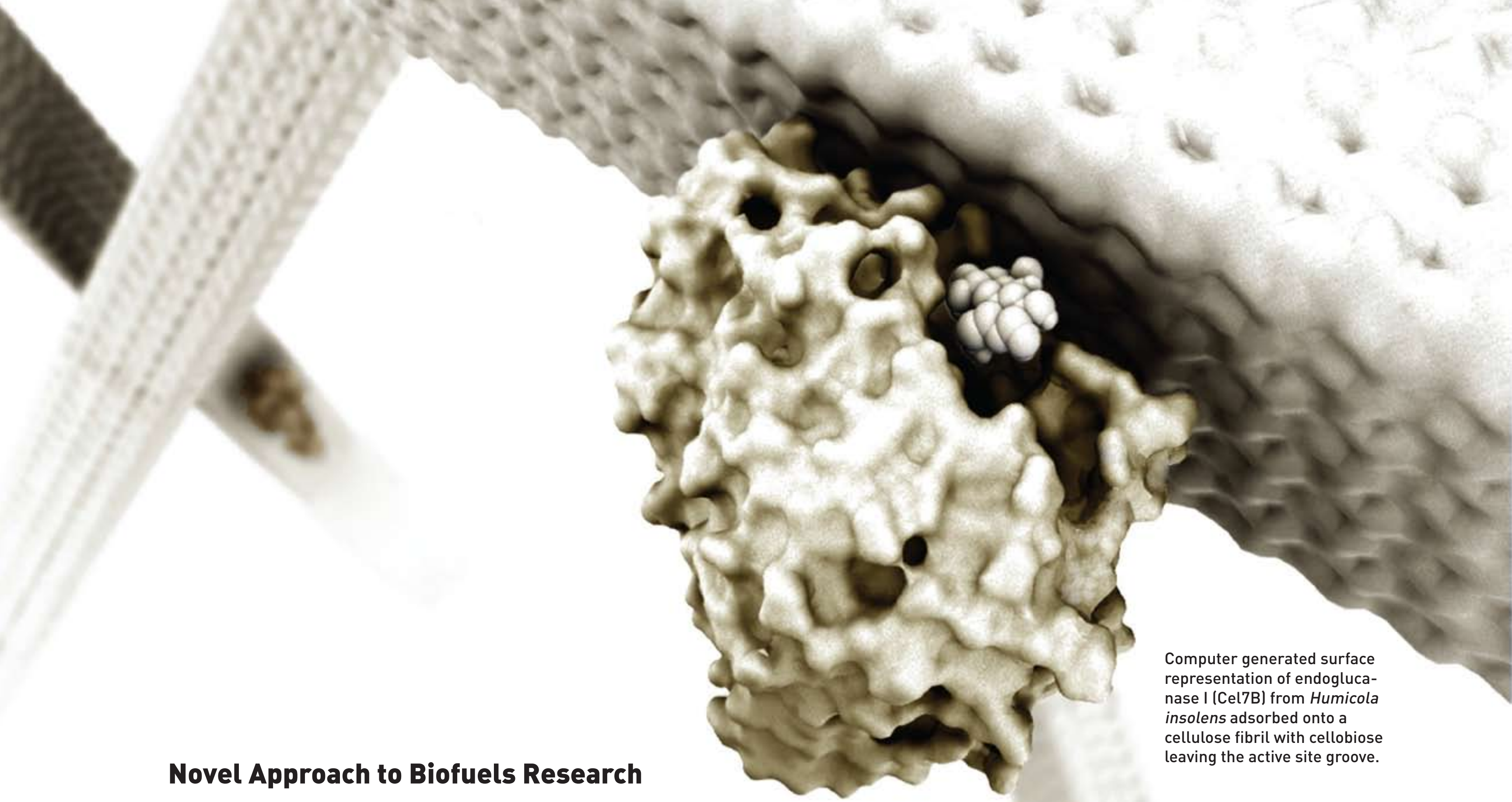
"Essentially, I use lasers as well as magnetic and electrical fields to create very small devices that function similarly to normal valves, pumps and mixers. Much of our work is focused on the use of optical techniques that mechanically squeeze individual cells," Marr said.

He first became interested in this work as a graduate student when he heard Steven Chu speak at a weekly colloquium. Chu later won the Nobel Prize in physics and is now U.S. Secretary of Energy.

"He showed how one could use lasers to grab onto little particles called colloids and move them around in a very controlled way without actually touching them. For those old enough to remember *Star Trek*, this is very much akin to a micro scale tractor beam. I realized then that I would base my future research program on this idea," he said.

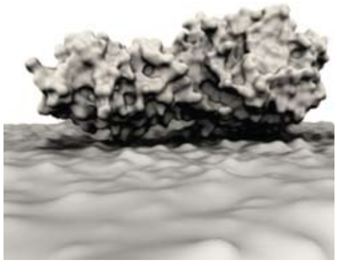
Marr came to Mines in 1995 after completing a two-year industrial postdoc with Raychem and earning a PhD in chemical engineering from Stanford University. He has since published 40 papers and, with his students, secured six patents. From 2009 to 2010 Marr received three NASA Inventions and Contributions Board Patent Application Awards. In 2007, he was honored with the Dean's Excellence Award.

Marr's research is funded by the NIH, the National Science Foundation and the State of Colorado Biosciences Discovery Program. The NIH funding includes a $1.3 million grant awarded in 2009 from the National Institute of Allergy and Infectious Disease to develop optical-trapping based instrumentation for cell mechanical property measurement.



Computer generated surface representation of endoglucanase I (Cel7B) from *Humicola insolens* adsorbed onto a cellulose fibril with cellobiose leaving the active site groove.

Novel Approach to Biofuels Research



Computer generated surface representation of cellobiohydrolase I (Cel7A) from *Tricoderma reesei* adsorbed onto the cellulose substrate.

Mark Maupin, a new professor in Mines' Chemical Engineering Department, is developing liquid transportation fuel from biofuels using novel approaches.

"Researchers will benefit from the increased understanding of the underlying physics that drives enzyme catalyzed reactions. Industry will benefit from a new cost effective alternative to the use of petroleum. Our global society will benefit from not only a reduction in greenhouse gas emissions, but also the creation of a renewable clean feedstock for liquid transportation fuels and value added commodities," Maupin said. "Utilization of cellulose for liquid fuel can achieve zero net carbon dioxide emission, thereby making it a crucial component in efforts to reduce greenhouse gases."

His research focuses on biofuels derived from lignocellulosic biomass, which are attractive alternatives for three reasons. First, there is the vast infrastructure already in place for the distribution of a liquid transportation fuel. Second, fuel derived from cellulose doesn't compete with human or livestock food resources. And third, since cellulose is the most abundant renewable biopolymer on earth, the feedstock for cellulosic biofuels is almost inexhaustible.

Enzyme understanding and testing are key to Maupin's work. Cellulosic biofuels are created by hydrolyzing cellulose to glucose and subsequently fermenting the glucose to make biofuel. Maupin says there are several major obstacles to the viability of cellulosic biofuels. A major barrier is the natural resistance of cellulose to enzymatic depolymerization, known as biomass recalcitrance, which is primarily responsible for the high cost of cellulosic biofuels. To overcome this, his group is modeling three enzymes that are involved in the hydrolysis of cellulose and evaluating their ability to bind substrate and catalyze the hydrolysis reaction.

The simulations will provide insights into the enzyme systems and open new possibilities to engineer more efficient enzymes. The information gained from the experiments will then be used in the next generation bioreactors, which could provide the nation with a renewable liquid transportation fuel alternative.

Maupin's research on biofuels is different from other research groups because it employs reactive molecular dynamics — a form of molecular dynamics simulation where the bonding topology is dynamically determined. Using this methodology, Maupin and his team can study the formation or breaking of bonds. The ability to couple chemical reactivity with the benefit of long time dynamical trajectories allows direct investigation of dynamical motions and interactions in addition to energetics on catalysis — a unique ability in the field of computational chemistry.

International Research Partnerships

In a continuing effort to expand research cooperation across the globe, Mines formally entered into two memorandums of understanding (MOU) with international universities in 2010.

Curtin University of Technology in Western Australia will work with Mines to expand the level of collaboration on minerals and energy education — and research between the two world-class mining research and education institutions — in an agreement called the "21st Century Earth Resources Initiative."

Linda Kristjanson, Curtin professor and deputy vice-chancellor for research and development, said the agreement will initially focus on strategic metals, CO2 sequestration and energy economics.

"Significant issues surrounding minerals and energy were once largely domestic concerns, but now they are truly international in nature and require an international response," Kristjanson said.

Initial research collaborations between Curtin and Mines will include the international availability of uranium, carbon dioxide sequestration and issues of energy economics for the minerals industry.

"Through this MOU, Curtin and Mines will focus on crucial areas in the minerals and energy space, including the world wide supply of uranium," said John Poate, vice president for research and technology transfer at Mines.

Mines also struck an agreement with Germany's Karlsruhe Institute of Technology (KIT), which formalizes a number of long-standing research collaborations, opens significant new opportunities, and will facilitate student and faculty exchanges between the two institutions.

With 20,000 students, KIT — located in southwest Germany — is one of Europe's leading universities in the natural sciences and engineering.

Ongoing collaborations and joint projects between Mines and KIT range from astrophysics to clean energy research. Natural synergies exist in strategic vision and academic strengths, with particular emphasis on advanced energy technologies.

Mines Technology Gains FDA Clearance

A lifesaving technology originally developed at Colorado School of Mines is now being marketed in the U.S., following clearance from the U.S. Food and Drug Administration (FDA).

The FDA granted clearance to MicroPhage, Inc.'s KeyPath™ MRSA/MSSA Blood Culture Test, which can deliver critical results within hours on patients infected with deadly antibiotic-resistant *Staphylococcus aureus* bacteria. In just five hours, using two small reaction tubes and a cassette containing two small test strips, the assay identifies whether blood culture specimens are infected with *Staph aureus* and determines if the culture has methicillin antibiotic resistance (MRSA) or susceptibility (MSSA). Without this technology the process can take up to three days and at times lead to patient mortality.

Currently, as many as half of all patients diagnosed with *Staph aureus* are initially prescribed the wrong antibiotics, contributing significantly to the thousands of deaths caused each year in the U.S. by antibiotic-resistant bacteria. Alone, methicillin-resistant strains of *Staph aureus*, known as MRSA, kill more than 19,000 Americans each year.

Kent Voorhees, professor in the Department of Chemistry and Geochemistry at Colorado School of Mines, and former PhD student Angelo Madonna developed the technology for the MRSA/MSSA Blood Culture Test — now trademarked by MicroPhage as the Bacteriophage Amplification Technology (BAT™). This technology exposes bacteria to antibiotics, delivering true phenotypic antibiotic susceptibility results.

"It is very satisfying to know that your scientific contribution will benefit society," said Voorhees. "The staff at MicroPhage should be congratulated because a very small percentage of start-up companies receive this honor."

In 2002, Voorhees and Jack Wheeler incorporated MicroPhage with the purpose of commercializing the technology, which was exclusively licensed from Colorado School of Mines.

Mines Director of Technology Transfer Will Vaughan called the FDA clearance a thrilling achievement. "As Mines continues to have scientific breakthroughs in a wide spectrum of disciplines, we remain committed to bringing them to market for the economic well-being of society."

MicroPhage, Inc.'s KeyPath™ MRSA/MSSA Blood Culture Test

Mines Instrumental in Bringing Solar to GE

The solar industry took a major step forward thanks to a bright idea starting at Colorado School of Mines and the Department of Energy's National Renewable Energy Lab (NREL).

In April 2011, General Electric (GE) purchased Arvada, Colo. based PrimeStar Solar, Inc. with the intent of scaling up production of PrimeStar's CdTe photovoltaic panel production line. The company's technology produces some of the most efficient CdTe solar panels ever made. With this technology, GE announced it will build the largest solar power plant in the nation.

Two of the founders and several of PrimeStar Solar's early key employees were trained in CdTe technology at Colorado School of Mines.

"This milestone puts us another step closer to having photovoltaics become a mainstream method of making electricity," said Dr. Joe Beach, professor of physics at Mines and one of the founders of PrimeStar Solar Inc.

"Mines' ability to produce high quality engineers and scientists with CdTe-specific knowledge has been an important part of the company's success," said Beach. "This will help give utility companies the confidence they need to invest in photovoltaic systems for the long term."

The record-setting panel was produced on the PrimeStar 30-megawatt manufacturing line. It was measured by NREL at a 12.8 percent aperture area efficiency. This panel surpasses all previously published records for CdTe thin film, which is the most affordable solar technology in the industry.

NREL transitioned the technology to PrimeStar through a cooperative research and development agreement signed in 2007.

Continually increasing solar panel efficiency is a key component of GE's goal to offer advanced solar products while reducing the total cost of electricity for utilities and consumers. In fact, a 1 percent increase in efficiency is equal to an approximate 10 percent decrease in system cost.

Professional Development for Grad Students

The need for a Center for Professional Growth has increased along with Mines' graduate population, which has grown from about 750 students in 2006 to more than 1,200 today. Through the center, graduate students will learn ways to balance their technical and professional skills, communicate more effectively and distinguish themselves from competitors for academic or industry positions.

Set for launch this year, the center will focus on "soft skills" for graduate students, such as time management, public speaking, research ethics and publishing. Dean of Graduate Studies Tom Boyd and Roel Snieder are spearheading the effort, and a team of Mines faculty has helped plan the center. Snieder is the W.M. Keck Distinguished Professor of Basic Exploration Science at the Center for Wave Phenomena.

The center will pull together courses and workshops from across Mines' curriculum. Approximately 90 percent of surveyed graduate students responded that the type of professional education the center will offer is "important" or "very important," and 74 percent responded that if they had known professional education was offered at Mines, they would have pursued it.

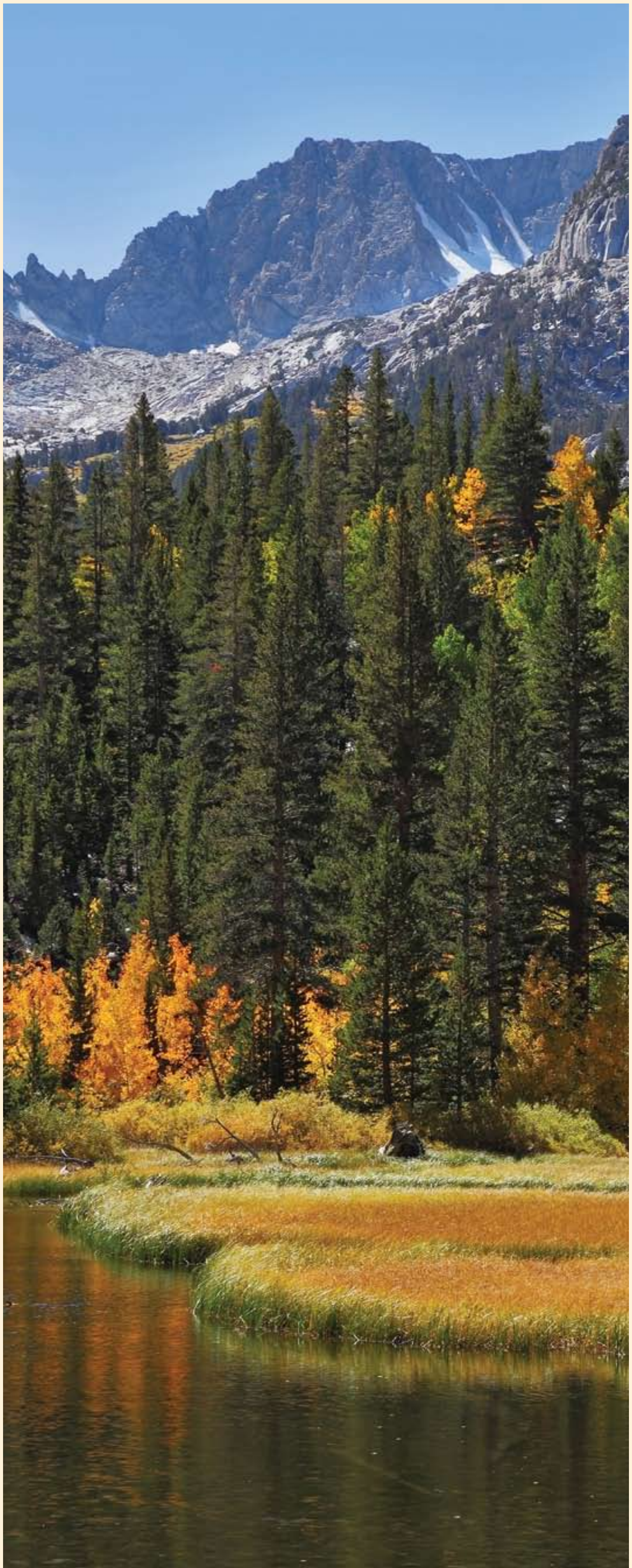
Abimbola Onasoga, a graduate student in Chemical Engineering, talks about her research during Legislative Day at the Colorado State Capitol.

"This indicates that advertising the availability of professional education helps students take better advantage of classes and training," said Snieder, who noted the center will establish Mines as a leader in graduate education while it also develops more competitive graduates.

Among the professional development courses Mines offers are Fundamentals of College Teaching, Academic Publishing, Professional Oral Communication, Introduction to Research Ethics, and The Art of Science, for which Snieder has co-authored the textbook *The Art of Being a Scientist; A Guide for Graduate Students and their Mentors* (Cambridge University Press, 2009).

"Our students have very strong technical expertise but we felt a real need to provide them opportunities to round out their education in more of the soft skills. The center is a way to pull these parts together, providing better advertising and better recognition for the activities we present, as well as leveraging those activities and impacting more graduate students with them," said Boyd.

Leading the Way in Hydrology Research



John McCray's work has made a significant impact on the hydrology field. A Mines professor since 1998 and named director of Mines' Environmental Science and Engineering (ESE) Division last year, McCray continues his research into fluid and chemical flow in surface and subsurface hydrologic systems. A few examples include studies on:

- the mountain pine beetle's possible impact on the hydrology, water quantity and water quality of mountain watersheds
- carbon dioxide injected into the subsurface to minimize the release of greenhouse gases into the atmosphere
- the treatment of wastewater contaminants by infiltrating them into soil
- cleaning up groundwater using physical, chemical and biological remediation technologies.

Among his contributions to the hydrology field are more than 50 peer-reviewed publications, included collaborative works with students, other Mines professors and research faculty. A few recent samples include an article about urban watershed hydrology for the *Journal of the American Water Resources Association*, an editorial about the joint sustainability of water resources and petroleum-energy production for *Ground Water*, and an article (in press) about remediation of Nonaqueous Phase Liquids source zones also for *Ground Water*. "A quantitative methodology to assess the risks to human health from CO2 leakage into groundwater" for *Advances in Water Resources* is in press and "Model evaluation of potential impacts of onsite wastewater systems on phosphorus in Turkey Creek Watershed" was accepted by the *Journal of Environmental Quality*.

John McCray

His work has also changed the face of Mines. McCray developed the Hydrologic Science and Engineering graduate program at Mines, an interdisciplinary program where students from any department or division can earn master's and doctorate degrees in hydrology. He served as the program's director for its first six years. Before coming to Mines, he earned a PhD from the University of Arizona. Prior to starting graduate school, he was a Navy nuclear-powered submarine officer.

"I have received some national recognition in my career, but the award I am most proud of is the Outstanding Faculty award for ESE last year given by the Mines Graduate Student Association and the Mines Alumni Association," McCray said.

Forecast Promising for Wind Tunnel Experiments

RESEARCHSPOTLIGHT

How could a wind tunnel at Mines help detect landmines?

Or investigate evaporation from soils? Tissa Illangasekare, and other Mines researchers and international collaborators, are using a one-of-a-kind wind tunnel testing facility to conduct innovative experiments related to the earth's surface.

"Even though the research for detection of buried objects is funded by the U.S. Department of Defense, the basic scientific findings will have direct humanitarian benefits toward solving one of the major problems of detection of buried land mines associated with past and ongoing military conflicts," Illangasekare said.

Water, and how it is stored and moved between the surface of the earth and the atmospheric boundary, is influenced by many processes and plays a crucial role in the hydrologic cycle and global water budget. This shallow subsurface zone, associated with emerging problems in hydrology, climate and the environment, is subject to natural and human-induced disturbances, resulting in continual changes in soil conditions and hydraulic and mechanical properties. The primary focus of Illangasekare's research is to fill fundamental knowledge gaps on the processes that occur in this critical zone. The new test facility at the Center for Experimental Study of Subsurface Processes provides a way for dynamic coupling of the atmospheric boundary layer to the land surface, enabling researchers to experiment with modeling.

Illangasekare says the research will help develop better conceptual models, modeling tools and characterization methods to address issues such as:

- detecting landmines, unexploded ordinances and tunnels
- understanding how climate effects the development of contaminant vapor intrusion pathways into surface and subsurface structures
- understanding the fundamental processes of freezing and thawing soils and how they effect the mechanical behavior, particularly in extreme climates
- investigating evaporation from soils and evapotranspiration from plants and vegetation to better understand water transfer between the land and atmospheres in climate modeling
- understanding leakage of geologically sequestered carbon dioxide through the unsaturated zone to the land surface, which has potentially detrimental environmental impacts.

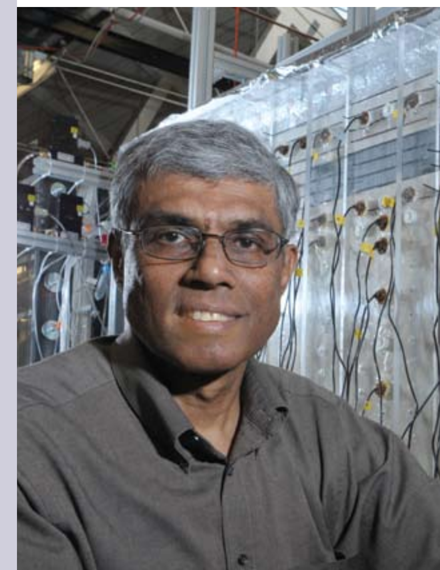
Incorporating complex feedback mechanisms between the land and the atmospheric boundary layer under controlled conditions in laboratory settings is a useful first step for validating basic theories on which models are built before field-testing and application. This approach makes models based on developed theories more reliable, giving them a clear advantage over studies that rely solely on field observations. The variables are many, including the influence on shallow subsurface soil moisture from daily temperature changes, evaporation, condensation, precipitation, liquid water flow and water vapor flow — factors that strongly influence each other. Using the research that will be conducted using this unique facility, the team plans to develop methods of quantifying soil moisture variability, both at high spatial and temporal resolutions, and upscale them to predict large field scale behavior. The research benefits range from addressing water related issues, global warming and climate change, to management of water resources.

KEY PLAYERS

Startup and initial research funding came from the **U.S. Department of Defense, U.S. Air Force Office for Science Research (AFOSR)**, and the **U.S. Army Research Office. Illangasekare** collaborated with wind tunnel testing expert **José Terrés-Nícoli** of the **University of Granada, Spain**, to develop the proposal. Additional funding was provided by **AFOSR** and is anticipated from the **National Science Foundation (NSF).**

AFOSR, Strategic Environmental Research for Defense (SERDP), the **Army Research Office** and the **Engineering Research and Development Center of the U.S. Army Corps of Engineers** funded research projects slated to be performed in the facility. Additionally, projects currently funded by **NSF** and the **Department of Energy** (through National Energy Technology Laboratory and Los Alamos National Laboratory) on carbon dioxide sequestration and leakage likely will be extended to use the facility. Researchers at Stanford working in the areas of carbon storage, environmental fluid mechanics, and subsurface processes plan to develop collaborations to use the facility, and Illangasekare's collaborators in Sweden and Denmark plan to use it also.

Aiolos Engineering Corp. of Toronto designed the wind tunnel, which required the architectural expertise of **Philip Greenburg** and the construction expertise of **Scott DeWees** of **Aberdeen Construction Inc. Mike Bowker,** associate director of capital planning and construction at Mines, managed the timely completion of the construction project. The unique facility drew the attention of **Los Alamos National Laboratory** and **Lawrence Livermore National Laboratory**, both of which are progressing on projects on carbon dioxide storage and leakage research.



TISSA ILLANGASEKARE

- **Professor of Civil Engineering**
- **AMAX Distinguished Chair of Environmental Science and Engineering**
- **Founding Director, Center for Experimental Study of Subsurface Environmental Processes (CESEP)**
- **Shimizu Visiting Professorship Faculty Fellowship, Stanford University (sabbatical 2012)**
- **Former Director, NATO sponsored Advanced Study Workshop on "Decision Support for Natural Disasters and Intentional Threats to Water Security," Croatia 2007**

Take a tour of the facility at researchmag.mines.edu or scan this code with your mobile device

Saving for a Cloudy Day

RESEARCH**SPOTLIGHT**

Robert Kee and **Rob Braun**

There's a problem with renewable resources such as solar and wind: They can't provide a steady, continuous supply of energy. That intermittency problem has researchers around the world working on creative ways to store energy so it is accessible when needed. Scientists at Mines are focusing on a large-scale energy storage project with a technology they are developing called a solid-oxide flow battery.

Mines Division of Engineering professors Robert Kee, holder of the George R. Brown Distinguished Chair, and Assistant Professor Rob Braun are collaborating with Scott Barnett, a professor of Materials Science and Engineering at Northwestern University, on the research project. Kee describes the research on the solid-oxide flow battery as a spin-off from investigations of solid-oxide fuel cells at the Colorado Fuel Cell Center. The center was created in 2005 with funding from the Governor's Energy Office and four partnering organizations and was designated as a Mines research center in 2006. Kee and Braun are members of the center's faculty.

Fuel cells, which electrochemically convert fuels such as natural gas to electricity, can be reversed so that the power flows both in and out. By supplying electricity to the fuel cell, it can be operated as an electrolyzer that produces fuel instead of consuming it. Then, using a unique concept in which the fuels are stored and recycled, the reversible fuel cell can be operated as a battery. In electrolysis operating (charging) mode, electricity is supplied to the solid oxide flow battery system and fuel is produced and stored in tanks. When power is needed, the system operation is reversed and fuel is fed from the storage tanks to the flow battery, which then generates electricity (discharge mode). In a large-scale grid energy application, the intent is to charge the flow battery during times of the day when renewable resources are available, but there is no demand for them. The solid-oxide flow battery provides a potentially cost-effective and efficient means to accomplish the critical objective of storing energy so that it is available for delivery when needed.

"Importantly, our analysis shows that the reversible operation can approach 80 percent efficiency – much greater than previously thought. However, although certainly very promising, it must also be said that this concept is still in early stage research and considerable development will be required," Kee said.

While research is being conducted throughout the world on fuel cells, and on reversible cells operating in electrolysis mode, the Mines/Northwestern project is unique in that it builds upon the idea of reversible solid-oxide fuel cells to make a high-efficiency battery. Importantly, the technology being developed differs from other electrolysis devices in that it operates at high temperature and is capable of both producing and directly utilizing hydrocarbon fuels, such as natural gas, which have high energy density. The high energy density fuel enables a lower footprint (i.e., land area) to accomplish a given amount of energy storage. The project advances many aspects of fundamental research in fuel cells, including ion-conducting materials, fuel reforming chemistry and optimal cell architecture.

A critically important aspect of the project is the system-level modeling effort that integrates the advanced cells into an optimal design that enables a high-performance energy storage system. The flow battery system contains not only the electrochemical cells that convert electricity to fuel or vice-versa, but also includes other components such as storage tanks, heat exchangers and pumps, which must work in concert to achieve high roundtrip efficiencies.

"The solid oxide battery cells are very efficient, and in order to retain that high efficiency, they must be properly integrated within the overall energy storage system," Braun said. "There are many challenges to achieving successful integration, including cell temperature control and managing the dynamics of mode-switching operation, but we are very excited about this promising technology."

IMPACT

With potential use everywhere electricity is required, the solid-oxide flow battery could transform both the distributed energy and electric utility industries, and simultaneously enable high renewable energy penetration into the electric grid infrastructure.

SOME DEFINITIONS

FUEL CELL: A device that directly produces electricity by combining a fuel, usually hydrogen, with oxygen

SOLID OXIDE: An ion conducting, solid-state ceramic electrolyte

FUEL REFORMING: The chemical processes that correspond to converting a hydrocarbon, such as methane (CH4), into a hydrogen-rich syngas and vice-versa

ELECTROLYZER: An electrochemical cell that uses electrical energy to reduce H2O (and/or CO2) into its primary elements, resulting in product gases, such as hydrogen and oxygen

CELL ARCHITECTURE: A material set that includes battery electrodes, electrolyte and other functional layers

SYSTEM-LEVEL MODELING: An activity that encompasses system design, simulation and optimization to predict overall operating characteristics, minimize costs and identify key design and operational criteria for the hardware within

GOOD TO KNOW

What makes a solid oxide-based battery/fuel cell device unique?

A flow battery based on solid oxide materials operates at high temperatures, which has the advantage of reducing cell inefficiencies by enhancing the reaction chemistry in both operating modes (i.e., charging and discharging). More conventional low-temperature electrolyzer-fuel cell combinations are not typically efficient in both operating modes.

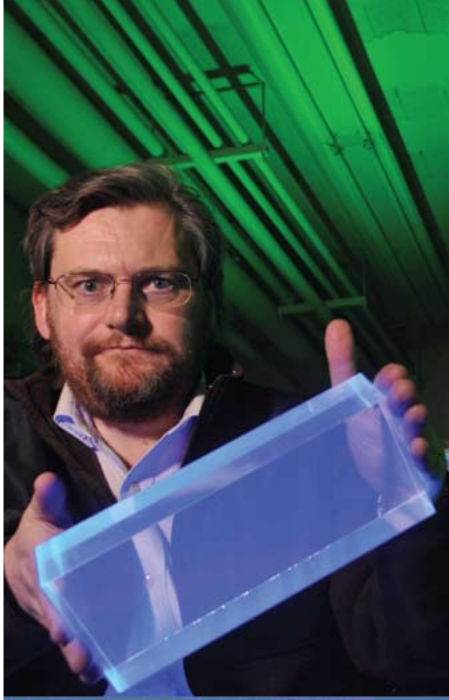
Furthermore, the high operating temperature also enables the direct production and utilization of high energy density hydrocarbon-based fuels, such as natural gas.

As a result, these devices possess unique flexibilities in that they can produce natural gas from excess renewable electricity, operate as peaking power plants, or store electrical energy in the form of a high energy density fuel and later discharge it during times of peak demand.

New Labs for Study of Nuclear Fuels

RESEARCH SPOTLIGHT

Uwe Greife



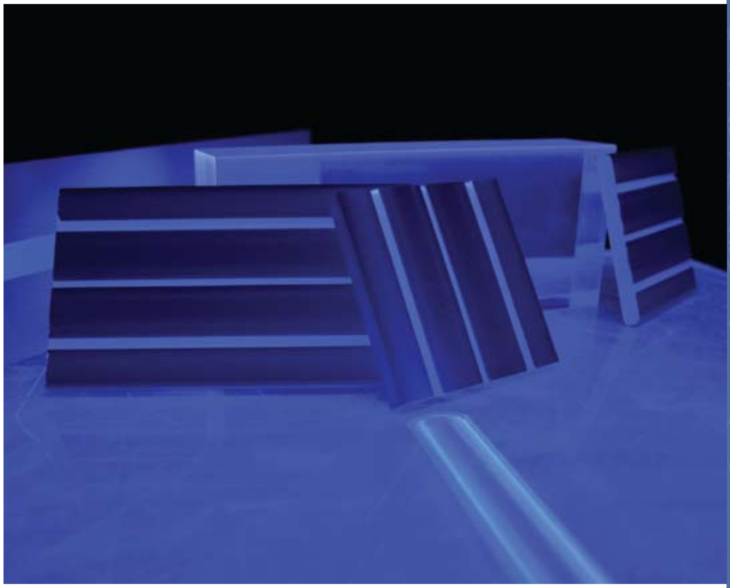
The Nuclear Science and Engineering Center (NuSEC) at Mines is only three years old, but it has already outgrown its space on campus.

The center was created to advance nuclear science and engineering research and to enhance the education of new and established professionals in the nuclear industry. Part of the center's research group will move into leased laboratory space at the U.S. Geological Survey (USGS) TRIGA reactor at the Denver Federal Center.

"NuSEC's dramatic growth, collaborative team and exciting future provides students with multiple opportunities to promote our understanding of the physical world and advance the benefits of nuclear technology for all of us," said Jerry Grandey, graduate of Mines and CEO of Cameco Corporation.

The new labs will dramatically increase Mines' abilities to directly study irradiated and radioactive materials and their properties. Jeffrey King, an assistant professor and interim director of the Nuclear Science and Engineering Program, said when complete, the new laboratories will make Mines one of only a handful of universities with direct access to electron, x-ray and optical microscopy capabilities dedicated to irradiated and radioactive materials and the only university incorporating all of these capabilities, combined with neutron imaging, in one location.

NuSEC Management Team Chair and Professor of Physics Uwe Greife said the move will give the team the opportunity to build a presence at Mines' partner reactor. King said the dedicated nuclear engineering laboratories will enable researchers to study the formation and properties of nuclear fuels using non-or slightly-radioactive simulant materials. Equipment there will provide capabilities for microscopic examination of radioactive materials, an x-ray ultra-microscope capable of 3-D sub-micrometer imaging and a digital neutron radiography imaging station with computed tomography capabilities.



Greife, who received the Colorado School of Mines Dean's Excellence Award in 2010, is focusing his research group on three activities: nuclear astrophysics, neutron-induced reactions and nuclear diagnostics.

"The uniting element in all our efforts is instrument development, which we try to apply to all fields where our involvement is beneficial," Greife said.

The research on nuclear astrophysics with radioactive ion beams involves experiments at a variety of nuclear facilities. The reactions pursued are usually relevant to nucleosynthesis — the formation of new atomic nuclei by nuclear reactions, which occur in stars and in the early stages of development of the universe — on the proton-rich side of the nuclides chart. The neutron-induced reactions involve developing experimental equipment (at the Los Alamos Neutron Science Center's beam facilities at the Los Alamos National Laboratory) for work relevant to nuclear energy and non-proliferation issues. The third area of research, nuclear diagnostic development, is being conducted for the National Ignition Facility at the Lawrence Livermore National Laboratory. The uniqueness of the nuclear ignition experiments necessitates creative approaches to diagnosing variables and outcomes.

"We are a very student-centered group dedicated to hands-on work. I train specifically for design, construction and test of hardware, de-emphasizing though still employing simulation. At Mines, we are training nuclear scientists who will become part of the nuclear security, defense and homeland security communities. Our detector developments will allow measurements of reactions for the nuclear energy and defense field, which will provide firmer predictions of the performance of nuclear systems," Greife said.

Funding for the research comes from the Department of Energy's Office of Science, Office of Nuclear Energy, and National Nuclear Security Administration; Lawrence Livermore National Laboratory, U.S. Nuclear Regulatory Commission, Oak Ridge National Laboratory, Department of Defense, Defense Threat Reduction Agency, and Idaho National Laboratory (via subcontract). The development of the new laboratory space is primarily supported by infrastructure funding from the Nuclear Energy University Programs, as well as by a Faculty Development Grant from the U.S. Nuclear Regulatory Commission.

GOOD TO KNOW

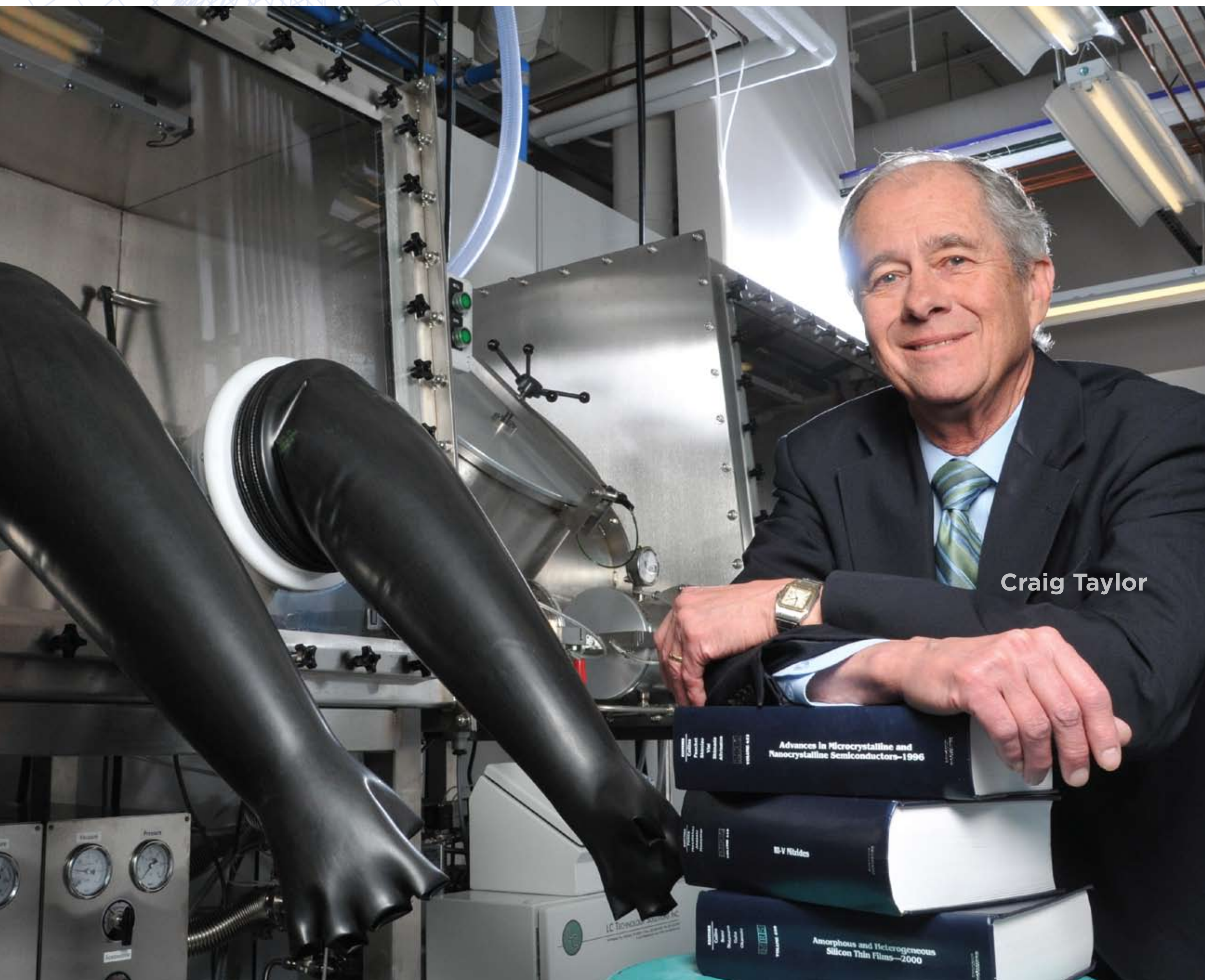
After the devastating earthquake and tsunami that struck Japan on March 11, 2011, **Jeffrey King** responded to many media inquiries and other requests for information about the **Fukushima Daiichi Nuclear Power Plant**.

In a summary of those remarks, King said, "The unfortunate events at the Fukushima Daiichi Nuclear Power Plant will necessarily bring considerable scrutiny to the design and operation of nuclear power plants, as well as the decisions and assumptions underlying the entire nuclear fuel cycle. These discussions must be robust to ensure that both industry practices and public perception of these practices are of the highest quality and well aligned.

Colorado School of Mines is well positioned to take an active part in these discussions. In particular, our emphasis on the nuclear fuel cycle is directly relevant to helping reduce the build-up of used nuclear fuel at reactor facilities, to the development of new fuel and structural materials that are better able to withstand challenging post-event conditions, and to improved radiation detection and monitoring technologies."

Advancing Materials for Renewable Energy Applications

RESEARCH**SPOTLIGHT**



Craig Taylor

The center at Mines with the long name — Renewable Energy Materials Research Science and Engineering Center (REMRSEC) — also represents a long list of areas of expertise.

In fact, director of REMRSEC Craig Taylor has said the broad spectrum of energy expertise at Mines — traditional fossil energy, nuclear energy and renewable energy — provides center researchers access to the richest set of ideas and perspectives on energy of any institution in the world.

"This center could make significant contributions to the efficient and clean production of electricity and fuels in the 21st century through scientific advances that dramatically improve the performance of renewable energy devices and systems. But perhaps the greatest impact will be the training of future generations of scientists and engineers in applications of renewable energy that will keep America competitive," said Taylor, who is also associate director of the Colorado Energy Research Institute.

REMRSEC is a close collaborative effort involving senior scientists from the National Renewable Energy Laboratory (NREL), located less than two miles from campus. Mines alumnus David Ginley is the lead NREL scientist.

The American public will be the major beneficiary from advances in materials for use in renewable energy applications. Potential benefits from the center's research include affordable electricity from the sun, efficient vehicles that run on alternative fuels such as hydrogen or methane, and economical storage of alternative fuels.

Each year REMRSEC supports a new research direction through a seed grant. This year the focus is on materials for use in next generation solar cells. The center continues to support prior selected research programs as well, including membranes for use in future generations of batteries and fuel cells, and materials for storing fuels such as hydrogen or methane.

The solar cell research is concentrated on silicon, not as it is used today in solar cells, but rather thin films consisting of very small "dots" of silicon whose individual sizes are on the scale of one billionth of a meter. These so-called nanostructures or nano-dots show great promise for dramatically improving the efficiencies of solar cells. Physics Professor Reuben Collins leads the solar cell efforts.

The membrane research is also focused on nano-sized structures, in this case mixtures of inorganic and organic materials. The organic materials usually operate with solutions that contain water and so cannot be run at temperatures above about 100 degrees Celsius. On the other hand, inorganic membranes must operate at temperatures above about 500 degrees Celsius to perform efficiently. Researchers hope that mixtures of inorganic and organic materials will provide operating temperatures between 100 and 500 degrees Celsius. Chemical Engineering Professor Andy Herring leads the membrane efforts with Metallurgical and Materials Engineering

RESEARCH PARTNERS

- Center for Revolutionary Solar Photoconversion (CRSP), a Colorado Renewable Energy Collaboratory Center involving Mines, NREL, the University of Colorado at Boulder and Colorado State University
- Ehwa Womens' University in Korea
- Eindhoven University of Technology in The Netherlands
- Imperial College in London
- Technical University of Norway
- Technion in Israel
- University of New South Wales in Sidney

EXTERNAL ADVISORY BOARD

- **George Crabtree**, chair, senior scientist and former administrator at Argonne National Laboratory
- **David Carlson**, chief scientist at BP Solar and inventor of the first amorphous silicon solar cell
- **Mildred Dresselhaus**, MIT professor and former chief scientist at the Department of Energy
- **David Eaglesham**, chief technology officer for First Solar
- **Andrew Gewirth**, professor at the University of Illinois at Champaign Urbana

Professor Ryan O'Hayre contributing on the inorganic membranes research.

For fuel storage, REMRSEC researchers are concentrating on open cage-like structures called clathrates, particularly on silicon in the clathrate structure. Carolyn Koh, an associate professor and co-director of the Center for Hydrate Research at Mines, leads this effort. Koh and her fellow researchers are experts on the clathrate structure of ice — the material that plugs underwater oil pipelines where it captures large quantities of methane. Recently the team successfully stored hydrogen molecules in clathrate silicon.

The National Science Foundation (NSF) funds REMRSEC through a $1.5 million annual grant. A second NSF grant, a grant from the Colorado Higher Education Competitive Research Authority, and funding from Mines provide additional support.

Among the center's other efforts are K-12 and undergraduate education and outreach, diversity and facility improvements.

The center developed renewable energy content for Mathematical and Computer Sciences Professor Barbara Moskal's K-12 teacher training programs. More than 20 Mines faculty and NREL scientists participate in this two-week summer program along with more than 20 graduate students who are associated with the center. This year, more than 125 applicants from around the country applied for approximately 10 summer fellowships. Another summer program, the Research Experience for Undergraduates (REU), provides renewable energy research experiences to undergraduate students. In the program's first two years, Mines students were the primary beneficiaries, but recently Physics Professor Chuck Stone has received a supplemental grant from NSF to provide these opportunities for students at other universities.

The center recently hired two new faculty members in the Materials and Metallurgical Engineering and Physics departments that increase the diversity among the faculty on campus. Also, REMRSEC made improvements to some of the centralized facilities on campus, including a remodel of the synthesis laboratory in Hill Hall, an upgrade (in progress) on the silicon processing facility in Meyer Hall, and a modernization of the characterization facilities in the General Research Laboratory.

MINES IN THE NEWS

COLORADO SCHOOL OF MINES (Golden, Colo.) – Responding to recent media inquiries, Mines experts have contributed their specialized knowledge to a broad range of stories in a diverse field of media. See a sampling on the following pages …

NE

New York Times

John Curtis, Department of Geology and Geological Engineering and Potential Gas Agency Director
Potential U.S. Natural Gas Supplies Have Jumped 3%, Industry Experts Say

Colorado Public Radio

Jerry Boak, Center for Oil Shale Technology and Research Director
Feds Revisit Oil Shale Environmental Review

The Denver Post

Joe Beach, Department of Physics
Colorado in running for site of nation's largest solar-panel factory

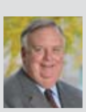
Colorado Public Radio

Mark Lusk, Department of Physics
Building a Better Solar Panel

Discovery Channel

Mines Students, Senior Design
StreetFlyer

Denver Business Journal



Bill Scoggins, Colorado School of Mines President
Colorado Leaders to GE: Bring plant here

National Public Radio

Robert Ferriter, Mine Safety and Health Program
Chilean mine rescuers face daunting challenge

National Public Radio

Will Fleckenstein, Petroleum Engineering Department
Panel: Cement tests should have raised doubts

The Denver Post

Robert Ferriter, Mine Safety and Health Program
Chilean rescue effort mining new territory in engineering, psychology

National Public Radio

Dan Kaffine, Division of Economics and Business
As Oil Prices Fall, What's Happening To Gas Prices?

Christian Science Monitor

Rod Eggert, Division of Economics and Business Director
China's lock on market for rare earth elements: Why it matters

New York Times

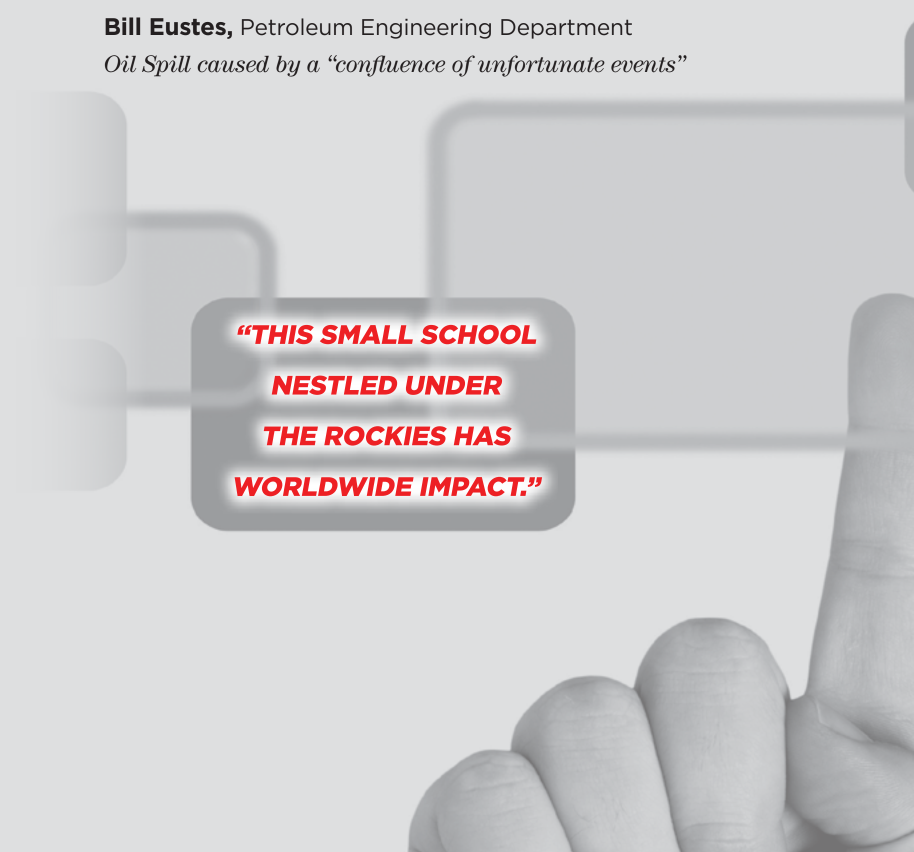
Murray Hitzman, Department of Geology and Geological Engineering, and **Rod Eggert**, Division of Economics and Business Director
Next for Afghanistan, the curse of plenty

CNN Anderson Cooper 360

Robert Ferriter, Mine Safety and Health Program
Training school for trapped miners

L.A. Times

Bill Eustes, Petroleum Engineering Department
Oil Spill caused by a "confluence of unfortunate events"



EWS

Christian Science Monitor
John Tilton, Division of Economics and Business
Chile mine rescue shows how far mine safety has come

Washington Post
John Grubb, Department of Mining Engineering
Experts say trapped Chilean miners should learn lessons of past disasters

Bloomberg BusinessWeek
Robert Ferriter, Mine Safety and Health Program
Massey has mines with more citations than blast site

Wall Street Journal
Rod Eggert, Division of Economics and Business Director
Pentagon in race for raw materials

Washington Post op-ed
John Curtis, Department of Geology and Geological Engineering and Potential Gas Agency Director
Shale gas: Hope for our energy future

New York Times

Matthew Posewitz, Department of Chemistry and Geochemistry
Exploring Algae as Fuel

AOL Daily Finance
Rod Eggert, Division of Economics and Business Director
Developing Afghanistan's mineral resources: A high-risk venture

New York Times
Bill Eustes, Petroleum Engineering Department
Democrats want chemical disclosure in gulf spill cleanup, containment efforts

CBS Money Watch
Bill Scoggins, Colorado School of Mines President
Colo. Leaders unite on potential solar panel plant

The Guardian (UK)
Carolyn Koh and Amadeu Sum, Chemical Engineering Department
Did deepwater methane hydrates cause the BP gulf explosion?

Discovery News
Robert Ferriter, Mine Safety and Health Program
Drilling to miners a slow slog

USA Today
Carolyn Koh and Amadeu Sum, Chemical Engineering Department
BP pursues short-term ways to stop leak

National Public Radio
Hussein Amery, Division of Liberal Arts and International Studies
Mideast water crisis brings misery, uncertainty

New York Times

Jennifer Miskimins, Petroleum Engineering Department
Colo. university launches center to study unconventional natural gas reserves

New York Times

David Matlock, George S. Ansell Department of Metallurgical and Materials Engineering
Many faces, and phases, of steel in cars

IMPACT IS THE **ISSUE**

JOHN POATE
VICE PRESIDENT FOR RESEARCH AND TECHNOLOGY TRANSFER,
COLORADO SCHOOL OF MINES

CRAIG BARRETT
RETIRED CEO/CHAIRMAN OF THE BOARD, INTEL CORPORATION

The integrated circuit industry has revolutionized the way we live. For over 50 years the industry has followed Moore's Law with a doubling of transistors, on a chip, every two years. Intel has been the exemplary company driving these remarkable advances in materials processing and circuit design. Their microprocessors are the backbone of the rapidly evolving computing and communications world.

I was fortunate to interview Craig Barrett, Intel's retired chairman, for this magazine. To any conversation, he can provide a unique business perspective. In addition, he can share his passion for education reform. And his belief in technology's role in raising social and economic standards around the world. And his commitment to investing in research and development.

My only problem was how to limit the questions. I've covered areas where Dr. Barrett has made – and continues to make – a profound impact, and I've asked some questions specific to our reading audience of Mines friends and supporters. I think you'll enjoy the results.

Our conversation follows.

John Poate

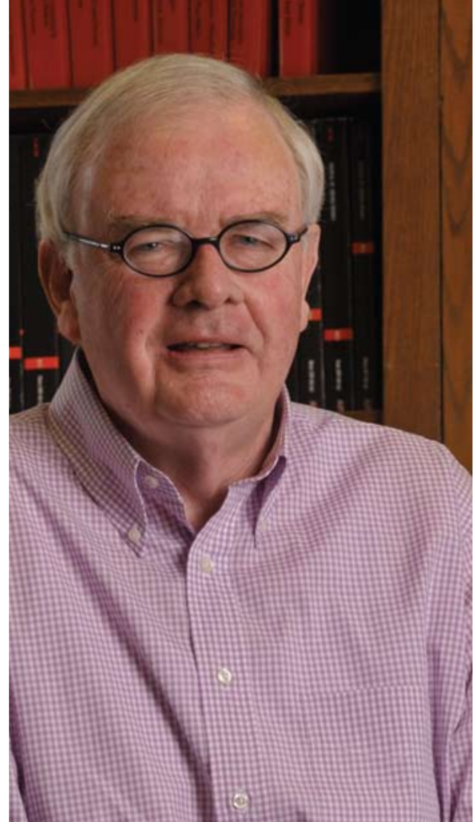
POATE: You have headed one of the world's most important and successful companies and have worked with such legendary figures as Gordon Moore, Bob Noyce and Andy Grove. What were the special drivers that brought all this talent together and keeps Intel ahead of the game?

BARRETT: Intel started at the beginning of the integrated circuit industry. Noyce, Moore and Grove were there at the start. The excitement was really Moore's Law where everything was doubling every 18 months or so – transistor count, memory density, processing power, etc. There are not many industries where things double on a continuing basis and the resulting products change the way the world works. Moore's Law was initially coined in 1965 and it is still going strong some 45 years later. As long as it continues to hold, there is still immense excitement and enthusiasm amongst the engineers and technologists. Intel adds to this excitement by spending immense sums on R&D and giving people a place to work where they can be world leaders in the technology.

POATE: Your knowledge and experience, as well as your energy and drive, could take you many directions. As one of your primary pursuits, you have zeroed in on improving education – particularly in science, technology, engineering and mathematics. If you had the power to transform one aspect of education in the U.S. today, what would it be?

BARRETT: The improvement of STEM education is absolutely key to our future competitiveness. If I could transform one thing in this space, it would be to get teachers in the K-12 system who really knew math and science, and could impart to the kids the power of these subjects. First, you can't teach math and science if you don't know the subject matter, and many of our teachers today have little expertise in these subjects. And, equally important, you can't get kids really interested and excited about the topic if you don't understand it in depth and love it yourself.

POATE: You're also an advocate for investment in research. How can the private sector effectively partner with our nation's public research universities in the competition for critical scientific and technological innovations?



JOHN POATE
Vice President for Research and Technology Transfer, Colorado School of Mines

- Earned a PhD in Nuclear Physics from the Australian National University
- Headed the Silicon Processing Research Department at Bell Laboratories
- Was Dean of the College of Science and Liberal Arts at New Jersey Institute of Technology
- Served as President of the Materials Research Society and Chair of the NATO Physical Sciences and Engineering Panel
- Chairs Lawrence Livermore National Laboratory review committees and is on the board of the National Renewable Energy Laboratory

BARRETT: I feel there are great examples of public/private partnerships in this space. Intel, for example, has research collaborations with well over 100 universities on a wide variety of topics. We exchange faculty and researchers in both directions. We use the universities as the base of much of our basic research. By the way, not only does Intel do this, but the entire semiconductor industry participates. Through the Semiconductor Research Corporation (funded by the semi industry), there are tens of millions of dollars of grants given to universities each year to pursue topics relevant to our industry. The universities are a critical part of our research establishment – partially funded by the industry and partially funded by the government.

POATE: How do you view the role of national laboratories in potential breakthrough research collaborations?

BARRETT: The national labs certainly play a role, although I believe the universities are probably more important. A critical area where the labs have played a role is in the development of the next generation lithography technology. Extended UV or soft X-ray lithography was a direct outgrowth of lab research. The main difference is that the universities are probably closer to the day to day problems of industry through exchange of researchers, faculty consulting, students moving back and forth, etc. There is less of this people movement between labs and industry, and consequently less interaction. Also, the spin-offs (start-ups) coming from the universities where you have students and faculties working with the venture capital community accelerate the flow of ideas and people from universities to the private sector.

POATE: Speaking of breakthroughs, what do you see as the next revolutionary technology?

BARRETT: This is always the tough question. Certainly we'll see continuations of the current trends – Moore's Law, greater bandwidth down glass fibers and through wireless technologies, smaller and smaller full-function devices, etc. But most of these are just extrapolations of Moore's Law behavior. Revolutionary technologies are always tougher to predict; for example, when will we see the next Internet; when will we see true thinking machines that anticipate our needs; when will speech recognition really be good enough to replace keyboards; when will flexible display screens that you can wear or really fold up be commercially viable. These are a few potentials. But there are also interesting questions at the fundamental core of the electronics revolution. When, and what, will replace the CMOS transistor as the next electronic switch so that we can keep chasing Moore's Law for another few decades? People are feverishly working on all of these topics (and more), but it is tough to predict when and where.

POATE: What do you know about Colorado School of Mines?

BARRETT: My first real contact at Mines was probably Dave Matlock following his graduation from Stanford.

POATE: Yes, Dave has told me you were one of his professors at Stanford and that you served on his thesis committee. I've also heard about some volleyball competition involving you two during that time! And, of course, Dave is also a member of the National Academy of Engineering. He is the ARMCO Foundation Fogarty Professor of Metallurgical Engineering here at Mines.

BARRETT: I actually started my undergraduate education in mining and metallurgical engineering at Stanford; then like most other metallurgical departments, there was a gradual move to other materials, broadening the scope of research activities. I don't think Colorado School of Mines is much different; certainly there are still interesting and challenging questions in metal extraction, but the field is much, much broader as materials comprise the base in just about every industry. And, with the cross fertilization (interdisciplinary) nature of most engineering fields, all metallurgical/materials schools have had to increase their scope.

POATE: Given the opportunity next fall to offer advice to the incoming freshman class at Mines, what would you tell them?

BARRETT: I would give them the same advice I give my grandkids who are about the same age. Get the best education you can and make sure you follow your heart – that is, do something you really enjoy. Talent in any field is defined by education and passion. With both, your services will always be in demand.

POATE: If you were starting your research career over again right now, what would you do?

BARRETT: When I was a student, the study of engineering was pretty well focused on individual disciplines. Today we have the collision of fields of study and there are immense opportunities to move in many directions. One only has to look at the interdisciplinary work in engineering and biology, for example. Transferring what we know about the field of materials to medicine and biology is immensely exciting. Equally exciting is what we can do with the ever-growing computing power that Moore's Law has brought to the individual researcher. Whether your goal is new materials development, indexing the human genome, creating new cancer drugs, etc., today we can do things that were unimaginable only a few years ago. But to answer your question directly, knowing what I know now, I think I would chase after the replacement to the CMOS transistor. The transistor replaced the vacuum tube as the fundamental electronic element about 50 years ago; and look how far we have come. We can only dream about what will happen with the next electronic switch – can we follow Moore's Law for another 50 years? And, if so, will the applications that touch humanity be as dramatic as we have seen in the last few decades? Some folks might want to cure cancer, or pursue stem cell-related cures, but I am hooked on Moore's Law and want to keep it alive and well.

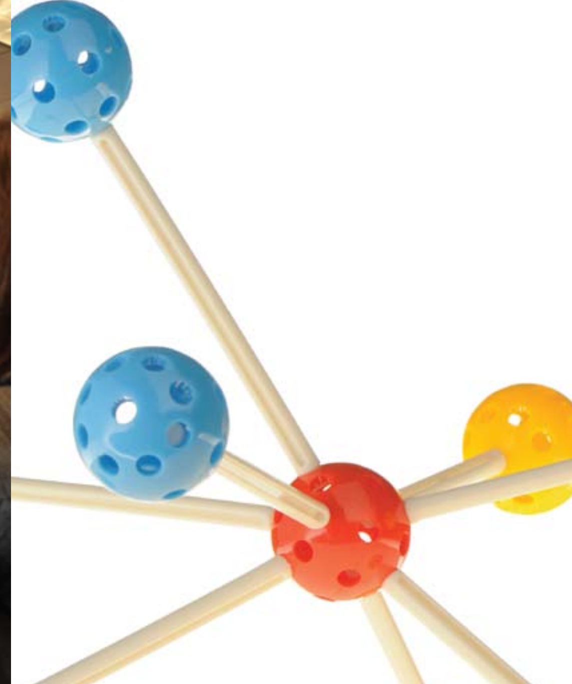
POATE: When can we get you to deliver the keynote address at a Mines commencement ceremony?

BARRETT: You just have to ask ... and then get by my executive assistant who has an iron hand necessary for scheduling all of my activities.

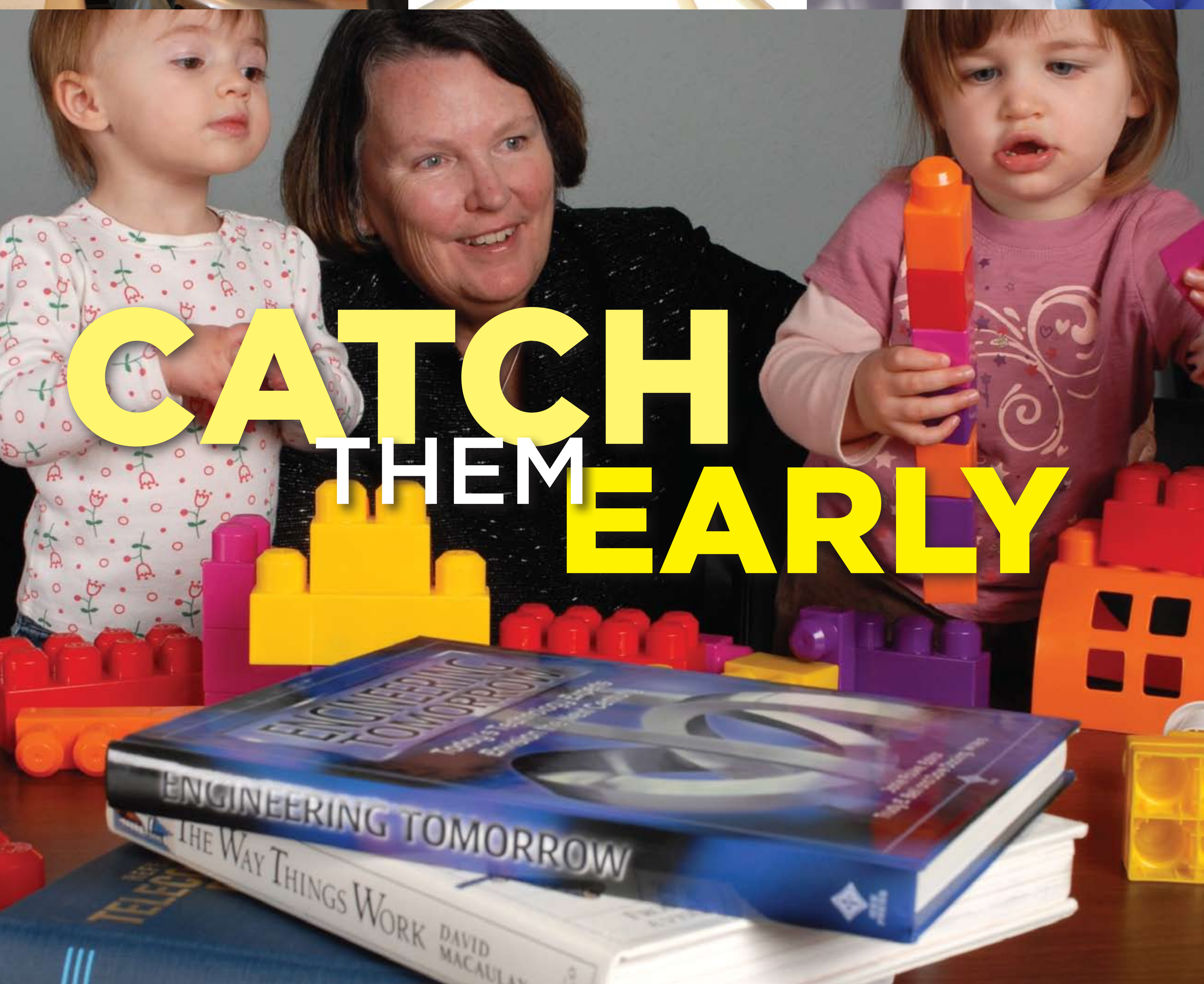
POATE: That's the perfect executive assistant. We will be persistent and convincing.

CRAIG BARRETT
Retired CEO/Chairman of the Board, Intel Corporation

- Earned BS, MS and PhD degrees in Materials Science from Stanford University
- Was associate professor at Stanford University in the Department of Materials Science and Engineering
- Joined Intel Corporation in 1974; held positions of vice president, senior vice president, executive vice president, chief operating officer, president, chief executive officer and chairman of the Board
- Served as chairman of the United Nations Global Alliance for Information and Communication Technologies and Development, bringing technology to developing countries
- Chairs Change The Equation, a national education science, technology, engineering and math (STEM) initiative



CATCH THEM EARLY



Meeting demand for scientists and engineers

The need for trained engineers and researchers in the U.S. has grown over the last several decades, and reports show that other countries have outpaced the U.S. in science and technology education. American students ranked 21st out of 30 in science literacy among students from developed countries, and 25th out of 30 in mathematics literacy according to the 2006 Programme for International Student Assessment (PISA) comparison. In an effort to spur education in the areas of science, technology, engineering and mathematics (STEM), President Barack Obama in 2009 launched the "Educate to Innovate" campaign.

"Reaffirming and strengthening America's role as the world's engine of scientific discovery and technological innovation is essential to meeting the challenges of this century," said Obama. "That's why I am committed to making the improvement of STEM education over the next decade a national priority."

KINDERGARTEN THROUGH HIGH SCHOOL

At Mines, numerous programs support and encourage the recruitment of the next generation of students to studies in science and engineering. Programs target students from kindergarten through graduate levels. Barbara Moskal, a professor of statistics in the Department of Mathematical and Computer Sciences and interim director of the Trefny Institute, said Mines is responding to the national need for more highly trained scientists and engineers in multiple ways and through several centers and institutes. On the K-12 level, the Center for Assessment (CA) in Science, Technology, Engineering and Mathematics (STEM) advances Mines' educational mission by providing ongoing evidence to support and improve programs. Through CA-STEM, several programs support outreach to the K-12 community, encouraging the next generation's interests and participation in science and engineering.

< Barbara Olds, Mines professor emerita and current NSF acting deputy assistant director for Education and Human Resources, plays with her granddaughters, Colette Olds, left, and Sophia Stillion.

Through a $2.5 million Bechtel Foundation grant, Mines works with Colorado's Adams County District 50 elementary schools supporting the district's hands-on and technology-rich instruction, and efforts are under way to expand the program to include school districts in Jefferson County. The National Science Foundation (NSF) supports Mines' efforts at middle schools as part of a $1.7 million GK-12 Learning Partnerships grant. ExxonMobil has provided funding to support rural Meeker County via interactive video. Colorado Department of Education, J.P. Morgan Foundation, Shell Oil Contributions, Boeing Corporation, ECA Foundation and Northrop Grumman have furnished matching funds for outreach efforts.

CA-STEM is part of the John U. and Sharon L. Trefny Institute for Educational Innovation, which distributes grants of $2,000 to $5,000 for curriculum innovation projects aimed to support quality and foster improvement in Mines' instructional programs. An endowment from former Mines President John Trefny and his wife, Sharon, funds the institute. A key element of the Trefny Institute is the Center for Engineering Education (CEE), which unites faculty interested in engineering education research.

UNDERGRADUATE EDUCATION

With a long tradition of excellence in undergraduate education for scientists and engineers, Mines is helping meet the demand for professionals in these fields.

"Mines has stepped up to the challenge by increasing its enrollment while simultaneously growing its infrastructure and faculty. Our curriculum has been expanded to include options in renewable energies, humanitarian efforts and environmental concerns. These areas are likely to appeal to a broad spectrum of students, increasing the diversity of the student body while improving and updating our programs," Moskal said.

An example of expanded programming is the Renewable Energy Materials Research Science and Engineering Center (REMRSEC), funded by the NSF and directed by Craig Taylor of the Physics Department. REMRSEC closely collaborates with the National Renewable Energy Laboratory (NREL), and together with alternative energy companies, has developed a Research Experience for Undergraduates (REU) program that nurtures and inspires undergraduate students to explore materials-related research in the field of renewable energy. For 10 weeks each summer, selected undergraduate students have the opportunity to work with REMRSEC researchers from Mines, NREL and local companies as they pursue renewable energy research.

"As a faculty member at Mines for many years, I was privileged to work with many innovative programs and activities, including Engineering Practices Introductory Course Sequence (EPICS), the McBride Honors Program, the Trefny Institute and the Center for Engineering Education," said Barbara Olds, professor emerita currently serving as the NSF acting deputy assistant director for Education and Human Resources. "In my current position at NSF, I appreciate the forward thinking that has been the hallmark of Mines' commitment to education at all levels. The school has a well-deserved national and international reputation in STEM education and education research. I know it will continue to nurture this part of its portfolio."

GRADUATE EDUCATION

Graduate enrollment at Mines has increased 60 percent over the last seven years, according to Dean of Graduate Studies Tom Boyd, and the quality of students accepted has risen as well.

"I believe we can document a significant change in the quality of the student body in terms of some of the standard metrics that measure quality, such as GRE scores," Boyd said.

Much of the growth has occurred in thesis-based and PhD graduate programs, corresponding to a parallel growth in research. Boyd said the type of research Mines graduate students conduct and how they are supported is fairly distinctive from other universities.

"When you look at CU's research portfolio, it's typically 90 percent or more federally funded. When you look at the Mines portfolio, currently about 40 percent of our research funding is private—that means it's coming from ExxonMobil, Chevron, Conoco Phillips and others. The remaining 60 percent is federal. This diversity in funding is distinctly different for Mines versus our peer institutions. The result is that our graduate students tend to do more highly applied research that is directly applicable to particular industry needs," Boyd said.

And that makes a difference in where graduate students end up after completing their degrees. Because Mines values industry jobs, and the institution prepares students to take high-level industry positions, many graduates do just that.

AND BEYOND

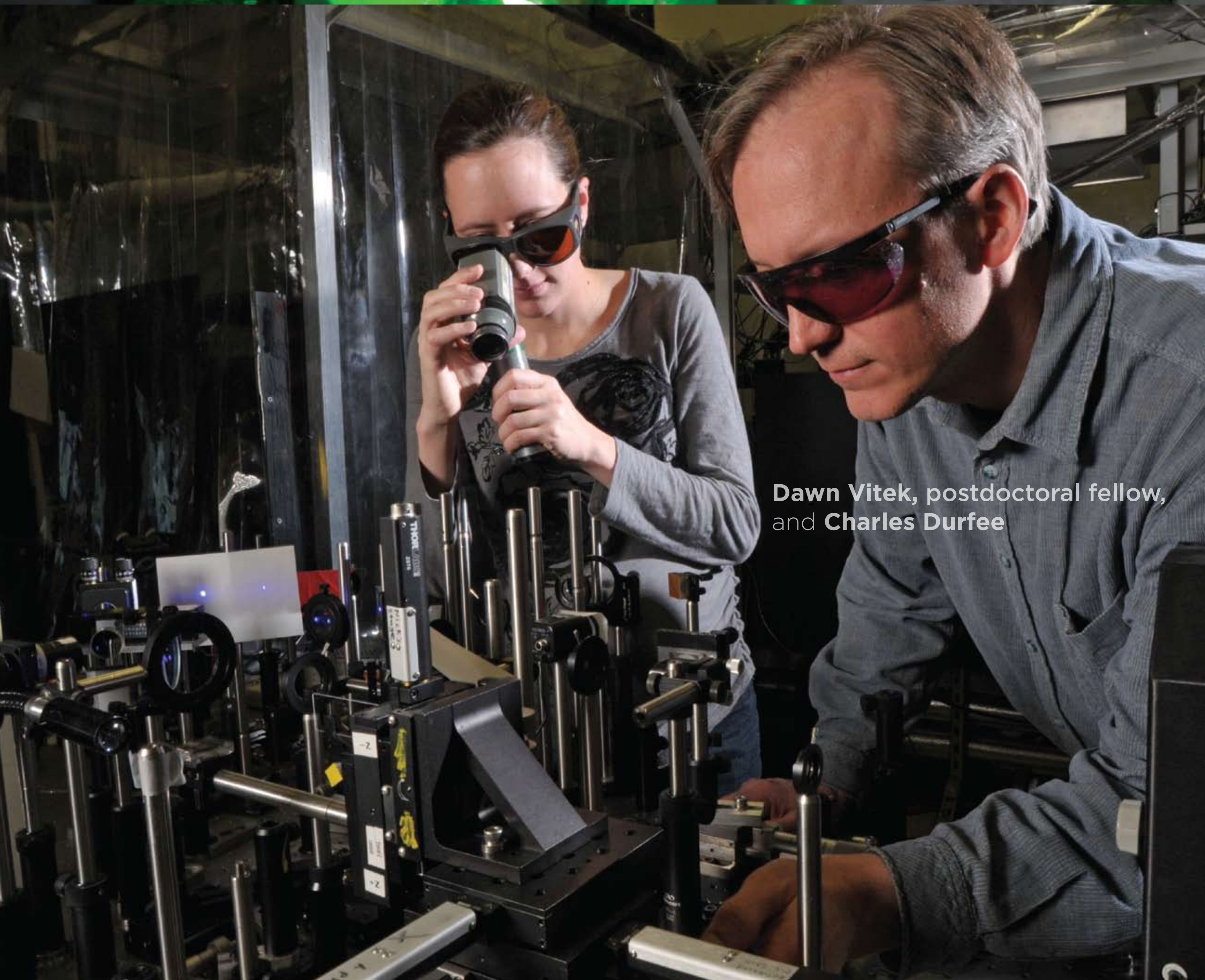
In 2010, Obama expanded the "Educate to Innovate" program by launching the nonprofit, "Change the Equation." Chaired by Craig Barrett, retired CEO and Chairman of the Board of Intel Corporation, the organization was tasked with bringing innovative mathematics and science programs to 100 or more high-need communities. Obama remarked that leadership tomorrow depends on how we educate our students today—especially in science, technology, engineering and mathematics.

"We know how important this is for our health. It's important for our security. It's important for our environment. And we know how important it is for our economy," Obama said.

ASKING QUESTIONS ELECTRONICALLY

Students who are reluctant to ask questions in science and mathematics classes often decide not to pursue careers in those fields regardless of how well they perform on tests. At Mines, a tool was created to overcome that barrier. Professor Frank Kolwalski in the Department of Physics developed InkSurvey, a Web-based software that supports electronic interaction between faculty and students during instruction. Even the most introverted students can ask questions in mathematics and physics courses without overtly interrupting the class. Assistant Professor Irene Polycarpou in the department of Mathematical and Computer Sciences is analyzing the software's impact. Once tested on a broader scale, InkSurvey will likely be used throughout undergraduate instruction.

LAB ON A CHIP



Dawn Vitek, postdoctoral fellow, and **Charles Durfee**

Laser pulses cut path to new health care technologies

"We are working to make small devices you can flow blood through and do different diagnostic tests on the blood inside this little chip. It's a little tiny laboratory that is chip-based. The idea is we could really create inexpensive health care devices for home use that are no more expensive and have no parts more sophisticated than a DVD player," said Physics Professor Jeff Squier, who is making advances in laser technology with Associate Professor Charles Durfee, also of the Mines Physics Department, and with Professor David Marr in Chemical Engineering.

Using a powerful new machining tool, they are cutting materials with a beam of laser pulses. What makes their work different is they are using super-fast laser pulses – each femtosecond pulse is just a millionth of a billionth of a second long – creating a very robust and controllable way to cut. This accomplishment has overcome previous limitations found in femtosecond micromachining.

"We focus the femtosecond laser pulses spatially *and temporally* (in space and in time). This has huge advantages in that it enables us to cut or make modifications deep within optically transparent materials with weakly focused beams of femtosecond laser pulses for the first time," Squier said.

The challenge is that a beam of laser pulses can be focused with a lens to an intensity that is high enough to change the material at the focus when it's cutting, drilling holes, making channels or even writing waveguides, like writing an optical fiber in a solid piece of glass. When the laser beam has to pass through something along the way to the smallest focal point, it can damage the material or get distorted before it reaches the target.

"What we're doing is manipulating the light in a way that localizes the intensity exactly where we want it. This makes what we're doing much more precise. To do this, we take advantage of the fact that our short pulses of light are made up of a wide range of wavelengths or colors. The pulse is only short where those colors are spatially overlapped. We separate the color components, then bring them to a focus so they overlap only at one point," Durfee said.

The technology has diverse applications ranging from rapid fabrication, such as 3-D lab-on-a-chip devices, to improving techniques in eye surgery, and creating home health care diagnostic tools. It also may be used in air or water where powerful laser beams are used in cutting or machining operations, such as in removing underwater debris. Ophthalmologists from the Colorado Health Sciences are working with the researchers regarding potential applications in laser eye surgery. The lab-on-a-chip research was partly funded by a joint grant with KMLabs, a laser company in Boulder, which will market the technology. Among the uses are home blood tests.

Funding for this research has come from the National Institutes of Health and the Air Force Office of Scientific Research through a grant with KMLabs Inc. Beyond immediate applications, this research could impact how laser devices are built in the future. Measuring is the key to this potentiality. The ability to literally measure how the light is focusing spatially and temporally gives scientists the confidence to predict what is going to happen with the devices they build. And that helps them optimize future designs. The research at Mines is distinctive, not only in that theoretical and computational modeling supports the design and helps in understanding the results, but also because it's unique in the world.

"We are the only group that has a comprehensive research program in this field. We help design the lasers, we design the optics, we rigorously characterize the focused light-matter interaction using techniques we have developed, and we develop real-world applications," Squier said.

CUTTING-EDGE

How fast is a femtosecond pulse?

A millionth of a billionth of a second long.

Go inside Jeff Squier's lab at researchmag.mines.edu or scan this code with your mobile device

NEW POWER PARADIGM

Douglas Way

Sabina Gade, postdoctoral fellow

Using a membrane to separate hydrogen and carbon dioxide

Rather than burning a carbon source for fuel, the new paradigm is based on taking the same resource (coal, biomass, natural gas or other hydrocarbons) and gasifying it instead. The process makes "syngas," a mixture of carbon monoxide and hydrogen. For that process to occur, hydrogen must be separated from carbon dioxide. Douglas Way, a chemical engineering professor at Mines, and his team of post-doctoral scholars and graduate students do this by making high-temperature hydrogen separation membranes.

"There are two important benefits of using a membrane to perform the separation of hydrogen and carbon dioxide. The membrane process produces a highly purified hydrogen product stream at lower pressure than the original feed mixture. When CO2 is concentrated, it is much more likely it could be sequestered or used in valuable ways, such as feeding algae/bacteria to produce diesel fuel, or for services, such as enhancing oil and gas production," said Way. "The trick with making synthetic membranes is to find materials where the gas you want to separate is highly soluble or where the structure of the materials allows the gas to travel through them faster."

Way and his group have the advantage of modern technology to help in their research, which builds on the discovery, by Scottish chemist Thomas Graham in the 1860s, that the metal palladium could dissolve hydrogen.

For two decades, Way has been working on metallic membranes for hydrogen separations. His current method involves forming a very thin layer of a hydrogen-permeable metal (typically palladium and its alloys) onto porous tubes. When a hydrogen molecule hits the surface, it falls apart and makes two hydrogen atoms. They diffuse right through the tube, pop out on the other side, and recombine when there is a difference in hydrogen partial pressure across the tube.

"To make a successful membrane, we have to do all of those things because we want the hydrogen to go through, recombine and come off the other side. I am interested in separating mixtures of gases. So I want to move the hydrogen from where it's in a mixture with something else and purify it and move it somewhere else, where we can do something with it. And that's what this whole power generation scenario is about," Way said.

There are already many commercial products that use palladium alloy membranes. Applications include oil refineries, purifying hydrogen for the manufacture of integrated circuits for computing, fuel cell power systems, portable battery packs and more. Because palladium is costly, Way's method of using thin films is an improvement that has received a great deal of notice in the research community. A paper about palladium membranes he and his fellow researchers authored in 1993 has been cited more than 150 times. He recently won a fellowship from the Australian Commonwealth Scientific and Industrial Research Organization to travel to that country to develop high temperature metal membranes from metals other than palladium and other platinum group metals (platinum, ruthenium, rhodium, etc.).

"I think in the next three to five years we will see more demonstrations of these thin film devices," Way said.

This research is supported by grants and contracts from the U.S. Department of Energy, U.S. Defense Department, and from commercial partners, including Chevron, the World Gold Council, the CO2 Capture Project, the Pall Corporation and Praxair.

UP IN THE AIR

The workings of a membrane are similar to those of a rubber balloon. Once let go indoors, a balloon filled with helium will float to the ceiling. It shrinks with time, and in a few hours the balloon will fall back to the floor. The balloon shrinks because the tiny helium molecules diffuse out.

An air-filled balloon will stay the same size for days because the gases in air, oxygen and nitrogen are much larger than helium so they permeate much more slowly through the rubber balloon.

VULNERABILITY AND POSSIBILITY

Study reveals resiliency of African youth

When James "Jay" Straker, an assistant professor in Mines' Division of Liberal Arts and International Studies, was nearing graduation from the University of Notre Dame, his heroes were travel writers. He wanted to be an adventurer and go to remote regions of the world. He learned to speak five languages other than English, achieving near native fluency in French. He joined the Peace Corps and soon found himself teaching English in the African nation of Guinea. Straker went on to earn a master's degree in English from Ohio State University and a PhD from Emory University. Through his years of study and since commencing his teaching career, he has spent four years in the Republic of Guinea, which has continued to inform his work.

His dissertation focused on Guinea, and he has since authored Youth, Nationalism, and the Guinean Revolution (Indiana Univ. Press, 2009) and numerous articles about youth, culture and postcolonial life in Guinea. His current research on Guinean youth is After Sékou: Youth, Vulnerability, and Possibility in Post-revolutionary Guinea. The title refers to the flamboyant dictator Sékou Touré, who led the country from its independence from France in 1958 until 1984, when Lansana Conté claimed power through a military coup. The nation had its first genuinely democratic presidential election in 2010, and Alpha Condé is the new president. Its neighbors to the south, Liberia, Sierra Leone and Ivory Coast, have endured two decades of civil wars that resulted in many refugees flocking to Guinea for safety through the late 1990s.

"The term 'vulnerability' in my project title is inspired by Guineans' intimate witnessing of the horrors of so-called 'small wars' or 'dirty wars' and by the ongoing vulnerability marking the day-to-day lives of the refugees. Guineans had participated in or endured totalitarianism since independence in 1958, and had experienced French colonialist domination for many decades before that. So, by contrast, there is a fair amount of hope in Guinea right now," Straker said.

His research was anchored in N'Zérékoré, a remote southeastern forest town 30 miles from the Liberian border, where he conducted semi-structured interviews with the sons and daughters of six "forestier" adults whose narratives featured centrally in his first book. Ages 17 to 25 at the time of the interviews, they primarily came of age after the death of Touré and during the times of turbulence created by neighboring wars. Straker asked them about school, home life, peers, popular culture, relationships and their observations about people, government and the future.

"My preliminary findings indicate that enduring and more recent historical circumstances have made these Guinean youth cautious observers and critical analysts of the havoc wrought by neighboring war, the relevance and disenchantments of national belonging, and the enigmatic consequences of globalization," he said.

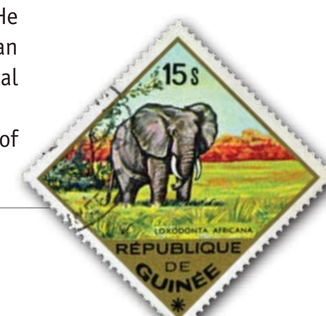
Culturally, the youth are quick to draw lessons or inspiration from music, much of which is produced locally, and also from imported films. Most young Guineans dream of traveling widely and are eager to gain an education despite their rather limited opportunities for employment. Straker said for the majority, the comforts of adequate food and shelter can seldom be taken for granted, and the pleasure afforded by a little pocket money or a cold drink is rare.

"Given the severely limited transportation possibilities, infrastructure and communication technologies characterizing most of the Guinean interior — where paved roads, running water and public electricity are the exception rather than the norm — Guinean youth have to exhibit remarkable degrees of physical and mental flexibility, versatility and stamina. Generally speaking, these are the capacities in which Guinean youth most greatly outdistance their American peers," Straker said.

Despite the lack of infrastructure, Straker believes most Americans would be pleasantly surprised by the quality of life in forest towns. Bolstered by vibrant ecology and agriculture, worldly openness, interethnic tolerance and remarkable resilience, these towns, he said, teem with generally healthy, knowledgeable and lovely people.

His current research has been supported primarily by a fellowship from the National Endowment for the Humanities. He also received a postdoctoral fellowship from the West African Research Association. His prior research was awarded a Social Science Research Council Fellowship.

Straker returns to campus this fall to teach Literatures of the African World, and Literature and Society.

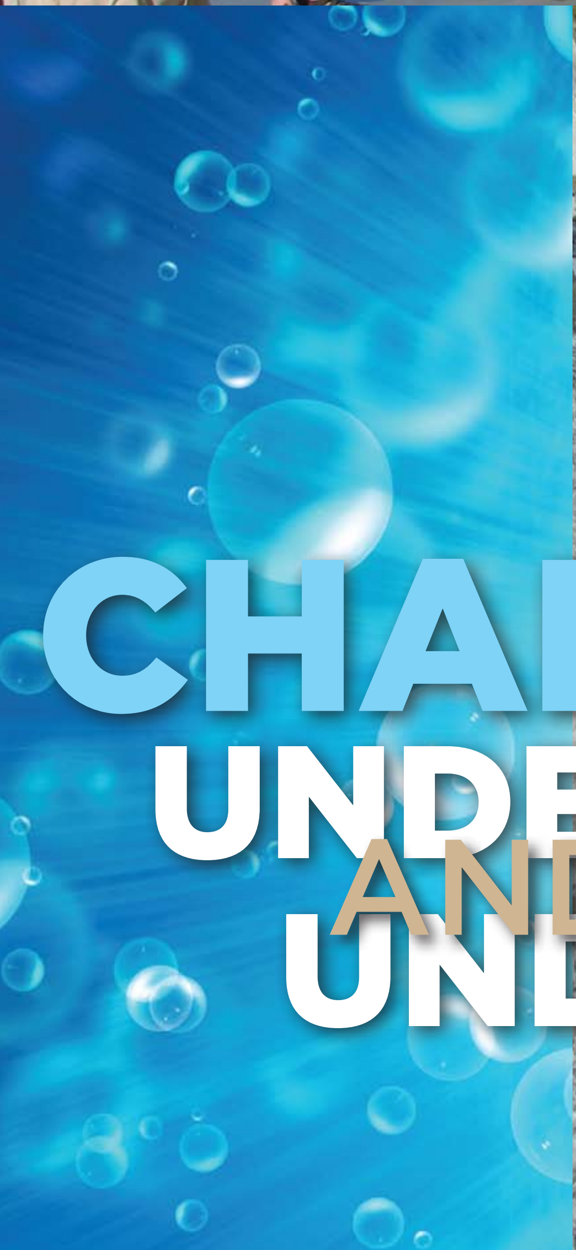


AlexanderZam / Shutterstock.com

FACTS ABOUT THE REPUBLIC OF GUINEA

Location: **Western Africa**
Capital: **Conakry**
Official Language: **French**
Population: **10,324,000 (2010 estimate)**
Economy: **Based on agriculture, mining and trade**
Exports: **Rice, bananas and coffee. Guinea is a major world producer of bauxite (the principal ore in aluminum). Guinea also has gold, diamond and uranium reserves**
Neighboring countries: **Sierra Leone, Liberia, Ivory Coast, Guinea-Bissau, Senegal and Mali**
For more, visit www.britannica.com/EBchecked/topic/248802/Guinea.

CHALLENGES UNDERGROUND AND UNDERWATER



Searching for and recovering fuels from difficult locations

Colorado School of Mines is recognized worldwide for its expertise in resource exploration and extraction. One of the areas where Mines excels is the upstream oil and gas sector, which involves searching for and recovering oil and gas from difficult underground and underwater locations. A number of scientists apply their expertise and Mines' resources to the challenge. In the Chemical Engineering Department, Carolyn Koh and Amadeu Sum specialize in hydrate research, including the occurrence of hydrate crystals in arctic and oceanic environments. In the Geology and Geological Engineering Department, David Pyles focuses on outcrops of sedimentary systems and Rick Sarg investigates low porosity carbonate reservoirs. Azra Tutuncu, in the Petroleum Engineering Department, works to enhance the fundamental understanding of formation characterization and fluid transport.

HYDRATE RESEARCH

Gas hydrates are solids composed of water cages that can trap natural gas molecules. Koh and Sum co-direct Mines' Center for Hydrate Research, studying gas hydrates in oil and gas pipelines to better manage their formation to prevent them from plugging flow lines. In another effort, the center is working on a project funded by the National Science Foundation (NSF) to understand the formation of hydrates from a deep water oil and gas blowout, such as the recent accident at BP's Macondo well in the Gulf of Mexico. According to Kohn and Sum, a fundamental understanding of the physics and chemistry of how hydrate crystals form from water, oil and gas in pipelines — and in the plume of a deep ocean oil spill — will be critical to advancing the technology to safely produce and transport oil and gas in subsea pipelines, and for effective containment of an oil spill.

"The scientific and engineering community will benefit from the fundamental research we are undertaking on droplet and particle dispersions, nucleation, crystal growth, aggregation, deposition, jamming and surface chemistry. The gained knowledge in these areas will be of significant benefit to the energy industry through the engineering data and models developed in the hydrate center," said Koh.

SEDIMENTARY SYSTEMS

Pyles directs and manages technical research at the Chevron Center of Research Excellence (CoRE) at Mines, where the current research focus is quantitative outcrop characterization. Researchers in this industry-academic partnership use outcrops to document how sedimentary systems evolve through time and space in a variety of settings. The oil and gas industry stands to benefit from this research. The more they know about sedimentary systems, the greater their level of confidence in data interpretation. For example, understanding hierarchical and fractal characteristics of sedimentary systems can significantly reduce uncertainty in interpreting sedimentary systems' subsurface data. The research also helps to address the challenges of connectivity, the ability for fluid transmission across stratigraphic boundaries, and reservoir quality. The quantitative approach Pyles' group uses in analyzing outcrops of sedimentary systems is unique.

"We are developing a mass-balance, moving-boundary approach to document how stratigraphic architecture of river systems relates to temporal changes in shorelines. Previous work on this topic is entirely qualitative, and as a result, predictions are speculative," Pyles said.

Over the last year, Pyles' team published six articles in peer-reviewed journals and 14 presentation abstracts at international conventions. Pyles won two awards from the American Association of Petroleum Geologists for best articles published in peer-reviewed journals and he garnered the presentation award for a poster at a Society for Sedimentary Geology conference. In addition to grants from Chevron, CoRE graduate and doctoral students have won 10 merit-based scholarships and grants from geological societies and petroleum companies.

CARBONATE RESERVOIRS

A carbonate reservoir is an underground oil or gas trap formed in reef, limestone or dolomite. Research Professor Rick Sarg says carbonate reservoirs comprise two-thirds of the world's hydrocarbon reservoirs and most of the largest oil and gas fields. Many of these fields are more than 50 years old and have given up their easy-to-flow oil and gas. Much of what remains is housed in low porosity, fractured reservoirs where fluid flow is difficult. Sarg and a team of Mines experts are developing a predictive model for carbonate pore systems and the fluid flow within them using geologic description, rock physics characterization and dynamic fluid flow experiments. This collaborative research uses carbonate rocks from ancient lacustrine limestones in Colorado and ancient marine carbonates from Abu Dhabi, Colorado and North Dakota. Improving recovery from a current average of 20 to 30 percent, by an additional 5 to 10 percent in old oil and gas fields would extend field life, defer further into the future the decline of oil and gas supplies, and provide more time for the development of alternative energy technologies.

"Developing predictive fluid flow models in carbonate reservoirs can benefit a number of different players across society. The oil and gas industry will benefit from having more predictive models of multiphase fluid flow to enhance recovery of oil and gas. Public efforts to sequester carbon through CO2 injection into deep subsurface reservoirs will benefit from understanding the long-term fluid flow characteristics of these reservoirs. Benefits may also accrue to ground water flow modeling by understanding potential pathways for pollutants," Sarg said.

RESERVOIR CHARACTERIZATION

Tutuncu holds the Harry D. Campbell Chair and directs the Unconventional Natural Gas Institute at Mines. She says advancements made in horizontal drilling, novel completions and hydraulic fracturing techniques — as well as improvements in exploration methodologies in recent years — have created opportunities to unlock vast resources in unconventional reservoirs previously considered uneconomical for production.

Key challenges include the need for enhancements in integrated reservoir characterization, greater understanding in stimulation and monitoring techniques, and improvements in environmentally responsible handling, processing and disposal of injected and produced fluids and in waste disposal. Tutuncu's research group aims to provide practical solutions by working to enhance fundamental understanding in a number of areas by investigating three scales:

- nano and micro scale measurements and modeling
- core scale measurements and modeling
- reservoir (field) scale measurements and modeling.

Tutuncu's group has established a new geomechanics laboratory to enable a variety of measurements under conditions similar to those in the field. They have also proposed establishing a field in situ laboratory dedicated to the fundamental scientific studies of gas and oil from exploration to production in gas shales and tight sandstones in Western Colorado's Piceance Basin. The in situ unconventional natural gas and oil research laboratory, coupled with the planned core and nano-scale measurements, will help nurture new engineering approaches for better recovery efficiency from unconventional reservoirs with continuous progress in environmental stewardship.

"The coupled experimental measurements not only enable us to measure real-time response of formations that will help in calibrating data collected in the field, such as seismic, microseismic data and well logs, but also help us understand the deformation, acoustic and failure characteristics of unconventional reservoirs coupled with the flow characteristics of the reservoirs," Tutuncu said. "The capabilities of Mines laboratories enable us to carry out complex problems involved in unconventional reservoir characterization and simulation in multivariate scale."

JOINING A LONG LINE OF EXCELLENCE

What makes a great research university? Its people. Colorado School of Mines has long been defined by faculty of the highest caliber. And the newest members continue to raise the bar. They are world-class academics — and they bring world-class talent.

IMPROVING **WATER QUALITY**

Sharp's research earns NSF CAREER award

Jonathan "Josh" Sharp, drawn to Mines' collaborative nature, joined the Environmental Science and Engineering Division as an assistant professor in January 2009. Sharp's work on water quality recently received notice from the National Science Foundation (NSF). The project, "Cleaner Water Through Microbial Stress: An Integrated Research and Education Plan," earned the Faculty Early Career Development (CAREER) award. His research efforts will be coupled with an educational plan designed to increase the engagement of undergraduates and K-12 students using regionally meaningful, hands-on education relating to environmental water quality.

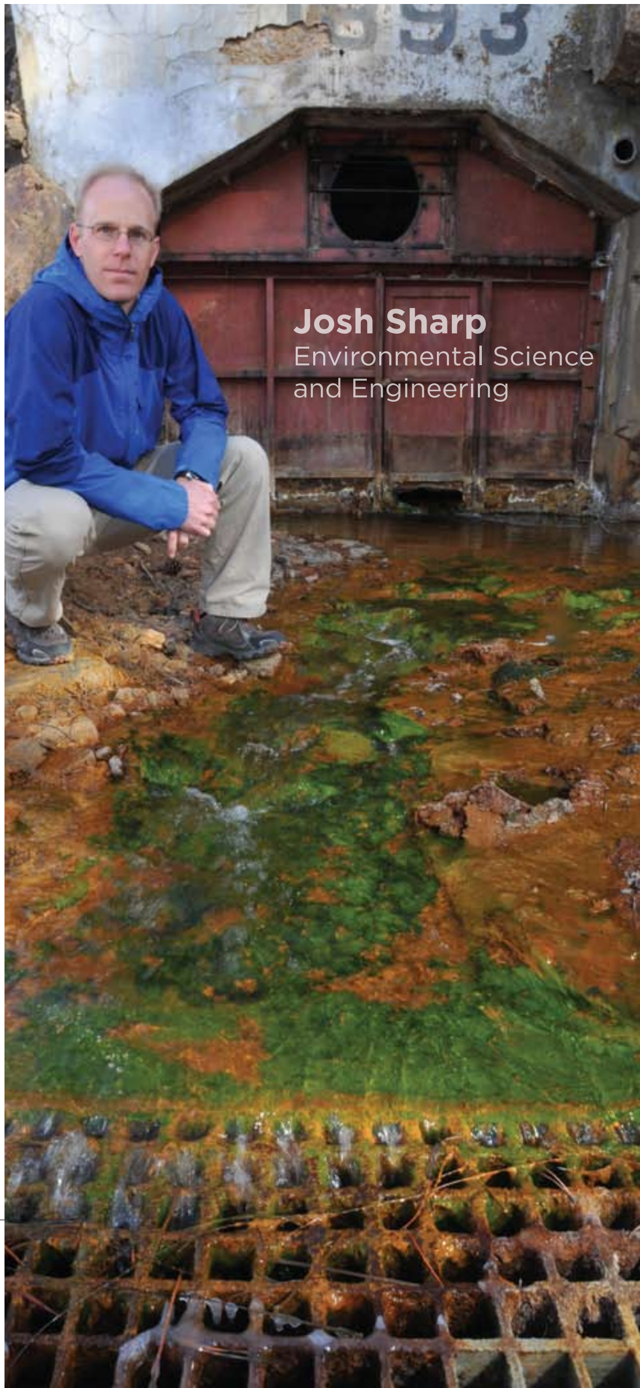
Sharp's research focuses on the impact of biological processes on water quality. He investigates how microbes can be used to more effectively clean contaminated sediments and water supplies (bioremediation) and to remove or immobilize mining-related metals, such as arsenic and uranium. He is also investigating how large-scale tree mortality caused by the mountain pine beetle may alter water quality in the Front Range of Colorado. His group uses a cross-disciplinary perspective that incorporates environmental engineering with biogeochemistry and molecular and microbiology. Sharp's research aims to provide fundamental understanding that will be useful for both policy and remediation.

This knowledge can be applied to treatment in managed natural systems such as aquifer recharge, riverbank filtration and wetlands to provide a cost, energy, waste-neutral and aesthetically effective tool for remediation when compared to more conventional treatment technologies.

"These systems have societal, environmental and economic advantages and address triple bottom-line, full-spectrum accounting: people, planet and profit. However, we need a better understanding of natural treatment processes if we are to exploit them for reliable and effective water treatment," Sharp said.

Sharp is a member of the Association of Environmental and Science Professors and the American Chemical Society. He has authored numerous peer-reviewed articles about the bioremediation of emerging organic pollutants and the bioimmobilization of uranium in water supplies. His research is supported by grants from NSF, the Department of Defense and industrial partners.

He holds a bachelor's degree from Princeton University and a master's and doctorate in civil and environmental engineering from the University of California at Berkeley. He pursued postdoctoral studies in environmental microbiology at the Ecole Polytechnique Federal de Lausanne in Switzerland prior to joining the Mines community.



Josh Sharp
Environmental Science and Engineering

ADVANCING **COMMON GOALS**

Collaborations lead to great science and technology

For many years Colorado School of Mines has enjoyed a close working relationship with the U.S. Department of Energy's National Renewable Energy Laboratory (NREL), also located in Golden, Colo. Dedicated to developing sustainable technologies to power the nation's homes, businesses and automobiles, NREL is the department's primary laboratory for energy efficiency and renewable energy research and development.

One of the ways Mines and NREL collaborate is through joint appointments that benefit both institutions. Among the latest Mines-NREL joint appointees are Corinne Packard and Gregory Bogin Jr.

Packard came to Mines from the Massachusetts Institute of Technology, where she earned a bachelor's and doctorate in materials science and engineering. She spends a quarter of her time as a staff scientist at NREL's National Center for Photovoltaics and the rest as an assistant professor in Mines' Department of Metallurgical and Materials Engineering. Packard studies the mechanics of materials used in renewable energy applications on the micro-and nano-scales to understand the microscopic origins of material failure. Materials such as membranes in fuel cells and thin films in photovoltaics must resist failure in the long term and in extreme conditions — high or fluctuating temperatures, exposure to the elements or corrosive gases, and voltages high enough to drive the migration of chemical elements.

"Flat-screen TVs and some solar cells share many of the same materials and a multilayered structure of thin films, but you wouldn't put your TV on your roof for 20 years and expect it would still work as well as the day you bought it. That solar cells can last this long is a feat of engineering, design and materials science. Our overarching goal is to connect material science structure-property relationships to real-world reliability," Packard said.

Greater understanding of material failure could provide strategies to engineer new materials to avoid such failures. Supporting the research are NREL, the Renewable Energy Materials Research Science and Engineering Center (REMRSEC), and start-up funds from Mines.

Bogin's research aims to improve fuel efficiency and reduce emissions in internal combustion engines. Through coupling experiments and computational fluid dynamics, he studies the use of alternative fuels and advanced combustion strategies. By understanding the role ignition kinetics play in controlling the combustion process, Bogin's research supports the development of advanced combustion engines, including the impact of using biofuels in such engines.

"The development of alternative fuels and advanced combustion engines with higher fuel efficiency and reduced emissions, including greenhouse gases, has the potential to benefit society as a whole, due to cleaner and more fuel-efficient engines, and to increase U.S. national security by reducing the country's dependence on imported oil," Bogin said.

Bogin earned a bachelor's degree from Xavier University of Louisiana and a master's and doctorate from the University of California - Berkeley. He joined the Chemical Engineering Department at Mines in 2008 as a post-doctoral researcher under contract with NREL. In 2009 he was promoted to assistant research professor in Chemical Engineering before taking a tenure-track assistant professor position in the Engineering Division in 2010. Through the NREL appointment, Bogin works with the Advanced Petroleum-Based Fuels team of the Center for Transportation Technologies and Systems. He devotes 15 percent of his time at NREL during fall and spring semesters and spends all his summers at NREL, where he conducts diesel and biodiesel fuels research.

Christian Frenzel
Mining Engineering

DIGGING **DEEPER**

Potential mining revolution

Before joining the Mining Engineering Department at Mines, Associate Professor Christian Frenzel worked for Herrenknecht AG, a leading manufacturer of tunnel boring machines and other mechanical excavation equipment. His work there included the development of the Shaft Boring System in collaboration with one of the world's largest mining companies, Rio Tinto.

His experience in designing excavation tools for industry led him to the work he does today —combining concepts from the mining field with ideas from the civil engineering world to develop new solutions for mining and tunneling. Frenzel's area of study is mechanical excavation systems, including the construction of deep mine shafts, development of underground mines, and tunnels for civil infrastructure, such as subways and roads.

"Mechanical excavation systems have the potential to create a revolution in mining due to a significantly shorter time for developing deep underground mines. That leads to significantly increased value of such projects. The best news is that this is improving safety for the workers," he said.

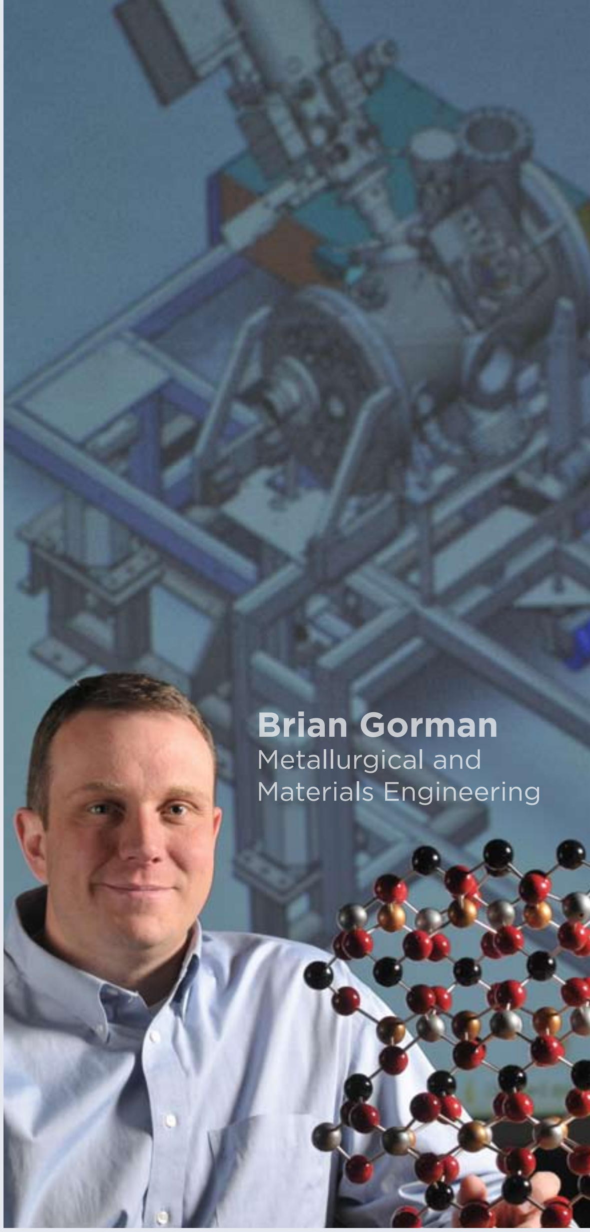
While mining companies and equipment manufacturers stand to benefit most directly from this research, improvements to excavation will help improve a variety of civil and industry projects in the long-term. For example, it could aid in meeting the demand for minerals since surface deposits are starting to deplete.

Mines not only has a long history of connections within the mining industry, it is home to a unique rock-cutting laboratory called the Excavation Engineering and Earth Mechanics Institute. The institute was established in 1974 to enhance excavation technology research and education. Test procedures and performance and cost prediction models developed at the institute have been validated with extensive field data from excavation and drilling projects around the world. Frenzel has access to several rigs there that allow for large-scale cutting tests for numerous applications.

This research is funded primarily by the mining industry. Equipment manufacturers have also provided smaller grants. Frenzel has applied to the National Science Foundation for more fundamental research, which is pending.

Several articles that Frenzel authored about mechanical excavation and cutting tools are published in peer-reviewed journals including, "Shaft Boring Systems for Mechanical Excavation of Deep Shafts," published in *Caving 2010* and presented in a talk at the International Symposium on Block and Sublevel Caving held in Perth, Australia. He is a member of the Society of Mining, Metallurgy, and Exploration; the American Society of Civil Engineers; and VDI German Association of Engineers.

Frenzel earned a master's degree from the Georgia Institute of Technology and a diploma in civil engineering and a doctorate from Technische Universitaet Muenchen in Germany.



Brian Gorman
Metallurgical and Materials Engineering

ONE **ATOM AT A TIME**

Microanalysis could yield revolutionary new tool

Imagine looking at something very, very closely. The paper these words are printed on. The metal on a car. A solar cell. Imagine if the eye could see materials at their smallest scale — one atom at a time. Brian Gorman and his team of researchers aren't just imagining. They're doing this.

An associate professor in the Department of Metallurgical and Materials Engineering, Gorman and his group study materials one atom at a time in 3-D. By studying materials on the atomic scale, the team will gather a more fundamental understanding of how to improve their electrical, mechanical and optical properties. Ultimately, the research will lead to improved methods of processing a wide range of materials.

The research got a boost last fall when the National Science Foundation (NSF) awarded Gorman and co-investigator Michael Kaufman a $3.5 million grant. Kaufman is head of the Metallurgical and Materials Engineering Department and directs the Electron Microscopy Laboratory. The grant supports development of an instrument that will revolutionize how materials are analyzed at the atomic scale.

"This one-of-a-kind instrument will be able to not only analyze the materials at an atomic scale, but also to analyze how the atoms move within a material. The instrument will combine both atom probe tomography and dynamic transmission electron microscopy into a single instrument," said Gorman, who has been invited to give more than 40 presentations about his research over the last five years.

It will be the first tool of its kind to enable 3-D imaging and chemical identification at the atomic level with ultrafast resolution, typically one billionth of a second. Studying these ultrafast atomic scale processes will enable advances in structural metals for aircraft and automotive applications, high-speed electronic devices, high efficiency solar cells and more.

When not looking at atoms, Gorman spends a great deal of time working with students to develop ceramic processing capabilities in the Colorado Center for Advanced Ceramics. At the end of the spring semester, students in several of his courses competed in a ceramic mug drop contest. Students created mugs from raw ceramic materials and competed by dropping them from successively higher levels. The student with the mug dropped from the highest spot — without breaking — won. Three of the best mug designs will compete at the annual Materials Science and Technology conference in October.

Gorman studied ceramic engineering at the University of Missouri-Rolla (now the Missouri University of Science and Technology), where he earned his bachelor's, master's and doctorate degrees.

TRACKING **CONTAMINANTS**

Mines professor trails chemicals through environment

Chemicals from common substances, such as stain-repellent fabrics and firefighting foams, have turned up in an unexpected place — the blood of people all over the globe. Why? Christopher Higgins, environmental Science and Engineering Division, is searching for the answer. He also wants to know about possible hazards.

"The biggest potential impact of my research is a better understanding of the potential human and ecological risks associated with the release of anthropogenic chemicals to the natural environment," said Higgins.

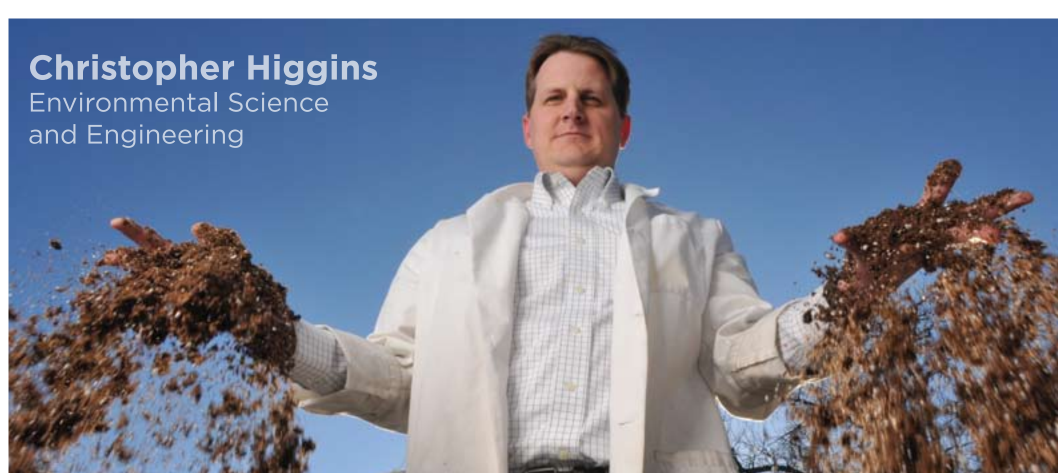
Higgins earned an undergraduate degree at Harvard University and a master's and doctorate at Stanford University, where he studied civil and environmental engineering. A former contractor for the U.S. Environmental Protection Agency (EPA), he brought his expertise to the department of Environmental Science and Engineering at Mines in January 2009. Higgins' research focuses on the movement of contaminants in the environment — how "emerging" contaminants are transported in natural and engineered aquatic systems, as well as their potential to bioaccumulate in organisms. Emerging contaminants under study in his lab include Teflon-like perfluorochemicals, nanoparticles, wastewater-derived pharmaceuticals and personal care products.

Of particular interest to Higgins are the factors controlling how perfluorochemicals transport in groundwater and their accumulation in plants and earthworms. Soil-dwelling organisms can be exposed to wastewater-derived chemicals when wastewater-derived sludge (biosolids) is used as crop fertilizer or when "recycled" water is used for crop irrigation. Given the increase in recycled water use in the dry Western U.S., these factors are a critical area of study.

How the pervasive and, in some cases, extremely persistent chemicals — from the perfluorooctanoate (PFOA) in stain-repellent fabrics and in some firefighting foams to the triclosan in antibacterial soaps — impact the environment isn't completely understood, but Higgins and other scientists are unlocking the clues. This knowledge will benefit government entities responsible for regulating such chemicals and cleaning up sites contaminated by chemicals such as PFOA. By examining the potential for transport and bioaccumulation of chemicals such as PFOA, the Higgins research group is helping explain why PFOA has been detected in the blood of humans from around the world.

When Higgins worked for the EPA, he was involved in revising the regulations concerning arsenic in drinking water and in monitoring unregulated contaminants. At Mines, his research group — employing state-of-the-art analytical techniques and experimental facilities — gains insight into the fundamental processes, occurring at a molecular scale, that are ultimately responsible for the observed macro behavior of chemicals.

Grants from various federal agencies, such as the U.S. Department of Agriculture, National Institutes of Health and Department of Defense, support Higgins' research. He has recently added to the field's growing body of knowledge by co-authoring several articles regarding chemical accumulations in soils.



Christopher Higgins
Environmental Science and Engineering

A **MESSAGE** FROM

MARCIA McNUTT

Director of the U.S. Geological Survey

Watch Marcia McNutt deliver the keynote address at Mines' spring commencement ceremony at researchmag.mines.edu or scan this code with your mobile device

As I look back on my first 18 months leading the U.S. Geological Survey, a time punctuated by numerous globally-significant earthquakes, a major U.S. oil spill, a volcanic eruption that brought trans-Atlantic air travel to a screeching halt, and more than the usual level of concern over international dependence on energy and strategic minerals, I am grateful for the broad and deep expertise of the USGS that permits this great agency to address both the foreseeable and the unforeseen issues confronting the nation. To do our job, we must continue to attract scientifically- and technically- savvy researchers and technicians who over the course of their careers acquire new skill sets and constantly remain relevant as problems wax and wane in importance and new solutions present themselves.

I had the very good fortune that my own career path allowed me to be a part of one of the finest institutions of science and technology education in this nation. A school very much like Colorado School of Mines that eats, breathes, and sleeps STEM: Science, Technology, Engineering, and Math. In fact, back when I was on the faculty at MIT, I remember being a good listener as my colleagues from other colleges would discuss the challenges of teaching geophysics without being able to use calculus. Then I would casually drop the fact that I taught geophysics using spherical harmonics, without the MIT students even blinking an eye. These conversations with my colleagues would remind me of the fact that there was an entire STEM-phobic world beyond my everyday life.

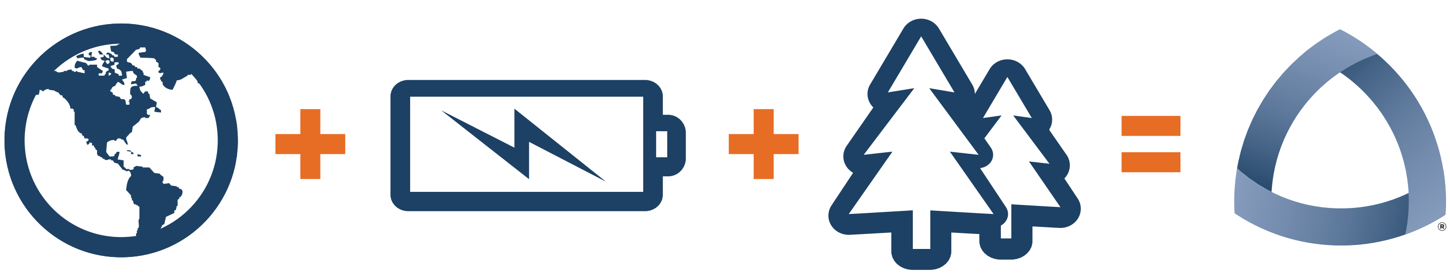
So why I am telling you this? Unless you have been in a coma for the last decade, you are probably aware that our nation is facing a crisis in the supply of STEM educated professionals. While schools like Colorado School of Mines continue to educate their students in these important areas which are essential for high-tech jobs, research, and education, other schools offer a bewildering choice in non-STEM majors and no guidance for students on job prospects for degree holders. I have concerns about where the US Geological Survey will find its workforce of the future, a workforce that needs to be far more diverse than our current staff if it is going to reflect America and solve the complex, interdisciplinary challenges of tomorrow. Simply consider the recent trend nation-wide that has closed down mining geology programs and reduced to a trickle the supply of graduates against the growing recognition that the U.S. should not become totally dependent on foreign sources of strategic minerals, such as rare earth elements.

What can be done to increase the STEM workforce, and ideally make it as diverse as America? Educational institutions have tried, through targeted scholarships and innovative educational programs. Government agencies have tried through internships and mentoring programs. Even private foundations and industry have attempted to solve the problem by investing time, talent, and resources, but the problem is still with us. One strategy we have not tried is to all work together, taking advantage of the strengths that each partner can provide in engaging students at different phases in their educational careers to develop an appreciation for STEM early on and continue to nurture it in a seamless handoff. Students need to be identified in junior high and involved in hands-on activities and mentor programs. They should be offered summer enrichment experiences that are meaningful and fun. They need good guidance in high school on course selection and possible supplementing of high school curriculum.

Willie Nelson said, "Mama, don't let your babies grow up to be cowboys." But what he forgot to say was please, let them grow up to be scientists or engineers. Working together, maybe we can make that happen.

Marcia McNutt is the director of the United States Geological Survey, the first woman to serve as director in the agency's 130-year history. She also serves as science advisor to the United States Secretary of the Interior. Previously Dr. McNutt served as president and chief executive officer of the Monterey Bay Aquarium Research Institute. Dr. McNutt earned a B.A. in physics, summa cum laude, Phi Beta Kappa, from Colorado College. As a National Science Foundation Graduate Fellow, she studied geophysics at Scripps Institution of Oceanography, earning a PhD in Earth Sciences in 1978. Among her many honors, Dr. McNutt is a member of the National Academy of Sciences, the American Philosophical Society and the American Academy of Arts and Sciences.

Colorado School of Mines
1500 Illinois Street
Golden, CO 80401



COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

mines.edu