



COLORADO SCHOOL OF MINES ENERGY AND THE EARTH

RESEARCH 2012-13

INTERVIEW:

ADMIRAL RICHARD TRULY ON LEADERSHIP

PAGE 28

PILOT Space Shuttles Enterprise and Columbia
COMMANDER Space Shuttle Challenger
COMMANDER Naval Space Command
LEAD Challenger Accident Investigation and Recovery
ADMINISTRATOR NASA
VICE PRESIDENT Georgia Institute of Technology
DIRECTOR National Renewable Energy Laboratory
VICE CHAIRMAN Colorado School of Mines Board of Trustees

RESEARCH LEADERSHIP AT COLORADO SCHOOL OF MINES



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

One characteristic that has defined Mines over the years has been its leadership in critical areas of education and industrial development. The school played a major role in establishing the gold and silver mining and refining industries in the earliest days of the state of Colorado. The expertise of the then tiny school was the catalyst that fueled the growth of Colorado. Since then we have grown considerably, but have always focused on our core strengths of applied science and engineering. This issue of our research magazine emphasizes the players — friends, faculty, students and alumni — who drive this leadership culture, and it describes three areas where we are making a worldwide impact:

UNCONVENTIONAL OIL AND GAS: Mines has been in this resource exploration and exploitation game longer than any other university. The shale gas ferment is changing the U.S. energy and manufacturing posture, and we are at the epicenter of the relevant education and research needs.

WATER: Conserving and maintaining water supply is one of the grand environmental challenges now facing the earth. The Mines research portfolio embraces and is at the forefront of some of the most critical issues, ranging from the urban water infrastructure on the Colorado Front Range and in the San Francisco Bay area to co-produced water from hydraulic fracturing for natural gas production.

SUPERCOMPUTING AND ENERGY: An investment five years ago in supercomputing has nucleated a campus-wide campaign to tackle and solve some of the toughest theoretical and computational challenges in the energy and environmental world. These computations cover the smallest nanometer structures to kilometer field studies.

We are breaking ground in other areas that might surprise people who do not know us. The energy and environmental areas on which we focus are smack in the middle of complex ethical issues. Two of our leading scholars have seized this opportunity to teach and inform our students of the ethical responsibilities and challenges in their chosen fields. On another front, our faculty and students are not only achieving academic success at ever higher levels, but are also pursuing entrepreneurial activities at an ever increasing pace.

Successful research and development organizations are guided by leaders of creativity and tenacity. We are privileged to feature two such legendary U.S. leaders, Admiral Richard Truly and Dr. Craig Barrett. My interview with Richard Truly covers some of his remarkable career and his thoughts on Mines. Craig Barrett, spring commencement speaker and a leader of one of the world's most important companies, provides a cogent message for students and faculty. Some of our leading faculty, who set the campus tone, are featured throughout the magazine. Students are critical to our success, and we have featured two examples of student leadership.

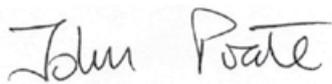
Alumni who are leaders in the research arena are important supporters of our agenda. For example, Dr. Bruce Clemens '78 of Stanford is president of the Materials Research Society, one of the world's trendsetting professional societies. Our winter commencement speaker will be Dr. Joe Gray '68, the Gordon Moore Professor and chair of Biomedical Engineering at Oregon Health and Science University and one of the nation's leading cancer researchers.

I trust that this magazine gives you a sense that we are in the middle of some exciting endeavors. We have the obvious challenges of competition and funding, but we can handle them. Our biggest challenge, in many ways, is to leverage and capitalize on the growth we are experiencing. Physical infrastructure needs to grow. More importantly, we need to redefine our academic structure for the future. To this end, Provost Terry Parker is leading the reorganization of the campus into three colleges, the first being the College of Engineering and Computational Sciences. These colleges will allow us to focus on our resources.

The competition amongst U.S. universities for media recognition is always fierce. We are doing well, especially in the frequent news articles on the demand for our students and the mind-boggling starting salaries they command. But I knew Mines had reached a tipping point when we were featured in the Dec. 8, 2011, issue of *Rolling Stone* in an article by Jeff Tietz, which starts with the phrase "Santiago Gonzalez, 13 years old and a full-time student at one of the nation's top engineering colleges..."

Mines leads again.

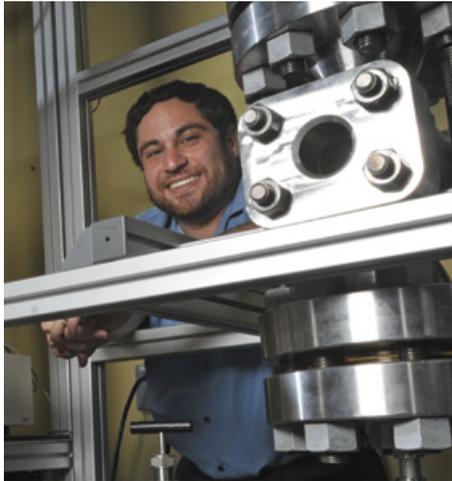
This landscape of the Manhattan skyline, pre-9/11, was created by Dr. David Eaglesham by dicing patterned silicon wafers. It is prominently displayed in Dr. Poate's office at Colorado School of Mines.



Dr. John Poate
Vice President for Research and Technology Transfer



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COLORADO SCHOOL OF MINES

ENGINEERING THE WAY

Colorado School of Mines is a uniquely focused public research university dedicated to preparing exceptional students to solve today's most pressing energy and environmental challenges. Founded in 1874, the institution was established to serve the needs of the local mining industry. Today, Mines has an international reputation for excellence in engineering education and the applied sciences with special expertise in the development and stewardship of the earth's resources.

MINES NUMBERS

5,200

Student body, undergraduates and graduates

\$47 million

Research awards in 2011, with 1/3 funded by private industry and more than half by federal agencies

1

Society of Women Engineers, largest collegiate section in the nation

90, 94, 98

Percentages of bachelor's, master's and PhD graduates placed upon graduation in 2010-11

\$65,000

Average salary offer to Mines graduates with bachelor's degrees in 2010-11

1

Public university in terms of starting salary, according to Payscale.com

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PRINTING

American Web
CPM Number #40065056

ISSN 2150-377X



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Fighting fire with fine water mist

This portable fire extinguisher is lightweight, inexpensive, non-toxic, recyclable, uses water more efficiently and is less damaging to structures and electronics than a typical sprinkler system.

“From the outset, Mines has been a leader in water mist technology, the basis of this chemical-free fire suppression system,” explained Angel Abbud-Madrid, director of the university’s Center for Space Resources. He led its initial development in collaboration with NASA. In early 2012, the extinguisher

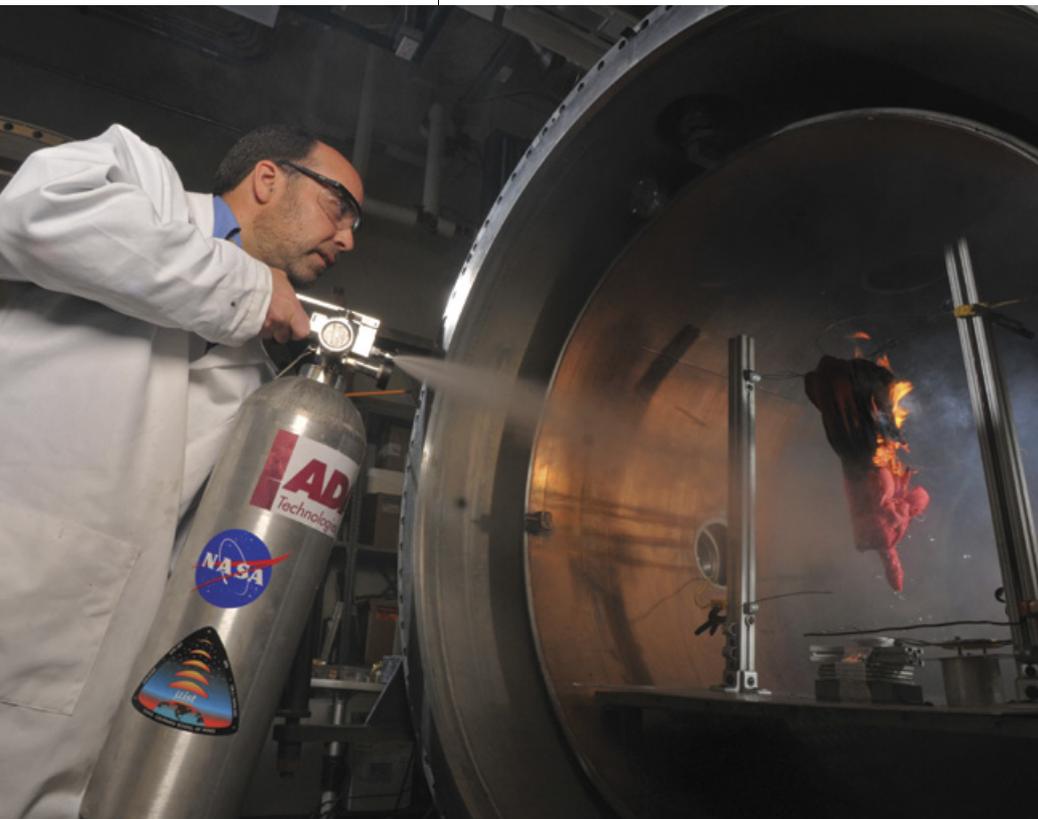
passed the System Requirements Review at Johnson Space Center.

From now on, all design and testing work are aimed at delivering a new fire suppression system for the International Space Station (ISS) by the end of 2013. Mines researchers will help with unit design and will conduct testing on campus, as well as on NASA’s zero-gravity airplane, to determine the extinguisher’s optimum configuration to put out an open fire inside an ISS module.

They are working with ADA Technologies, Inc. on product development and with Wyle Integrated Science and Engineering under NASA’s bioastronautics contract to build 13 units that will replace the existing CO₂ extinguishers on the ISS. The new units must fit in the same space as the old ones.

Once the installation on the ISS is complete,

the technology can move from spacecraft to commercial applications for a broader market. Possibilities include civil aircraft, passenger ships, military vehicles, subway systems and tunnels, museums and historical sites, health care facilities and computer rooms.



Angel Abbud-Madrid

Communication necessary to reach the summit

Erik Weihenmayer, the only blind man in history to reach the summit of Mount Everest, was the keynote speaker at the fourth Mines Leadership Summit held on campus in January. Weihenmayer made his historic Mount Everest summit in 2001. In 2008, when he stood on top of Carstensz Pyramid, the tallest peak in Australasia, he completed his quest to climb the Seven Summits – the highest peak on every continent.

Mines President Bill Scoggins described Weihenmayer as a “truly inspiring, innovative and accomplished individual.” This year’s program of speakers, team-building exercises and breakout sessions focused on the importance of effective communication in leadership situations. As the president shared his personal list of Top 10 Leadership Competencies with the group, he noted that communication skills include listening skills.

The Leadership Summit began in 2008 as a project led by the Mines student government with faculty and staff support, and since that time hundreds of Mines students have applied these experiences to their leadership roles in clubs, activities and academics.



President Scoggins made sure climber Erik Weihenmayer left this year’s Leadership Summit with a Mines hard hat.



Too much information



Michael Wakin received a Career Award this spring from the NSF Division of Computer and Communication Foundations.

“A significant byproduct of the modern Information Age has been an explosion in the sheer quantity of data demanded from sensing systems.” That first line in the National Science Foundation Career Award abstract lays out the problem. Then the abstract describes the solutions Principal Investigator Michael Wakin will seek: “This project focuses on developing effective new frameworks for data acquisition, processing and understanding that will help meet the technological challenges posed by this ever growing demand for information.”

Totalling \$400,000 over five years, the award is titled “New Models, Representations and Dimensionality Reduction Techniques for Structured Data Sets.” As Wakin, a professor in the Mines Department of Electrical Engineering and Computer Science, explained, “Fortunately, the information contained within a high-dimensional data set frequently can be characterized by some sort of concise, low-dimensional model.”

Wakin has always liked math, and he looks forward to the K-12 educational outreach integrated into his project. Such as Mines’ Tech Camp for middle school students. In a fun summer camp environment, he will have the chance to show students the challenges and possibilities of a math-oriented career — perhaps discovering ways to manage the huge quantities of data found in today’s information-rich world.

Polarization invention can aid in cancer detection, see through clouds

The development of a new circular polarization filter by a collaborative team of scientists at Mines and ITN Energy Systems has the potential to aid in early cancer detection, enhance vision through dust and clouds and improve moviegoers’ 3-D experience.

“A wealth of knowledge is contained in the polarization information of light, and accurately measuring this state of light has a number of interesting applications,” said David Flammer, Mines physics professor.

When measuring the different properties of light, the naked eye can see in color but cannot differentiate between different polarizations. This new invention allows users to measure the polarization state of light quickly and efficiently

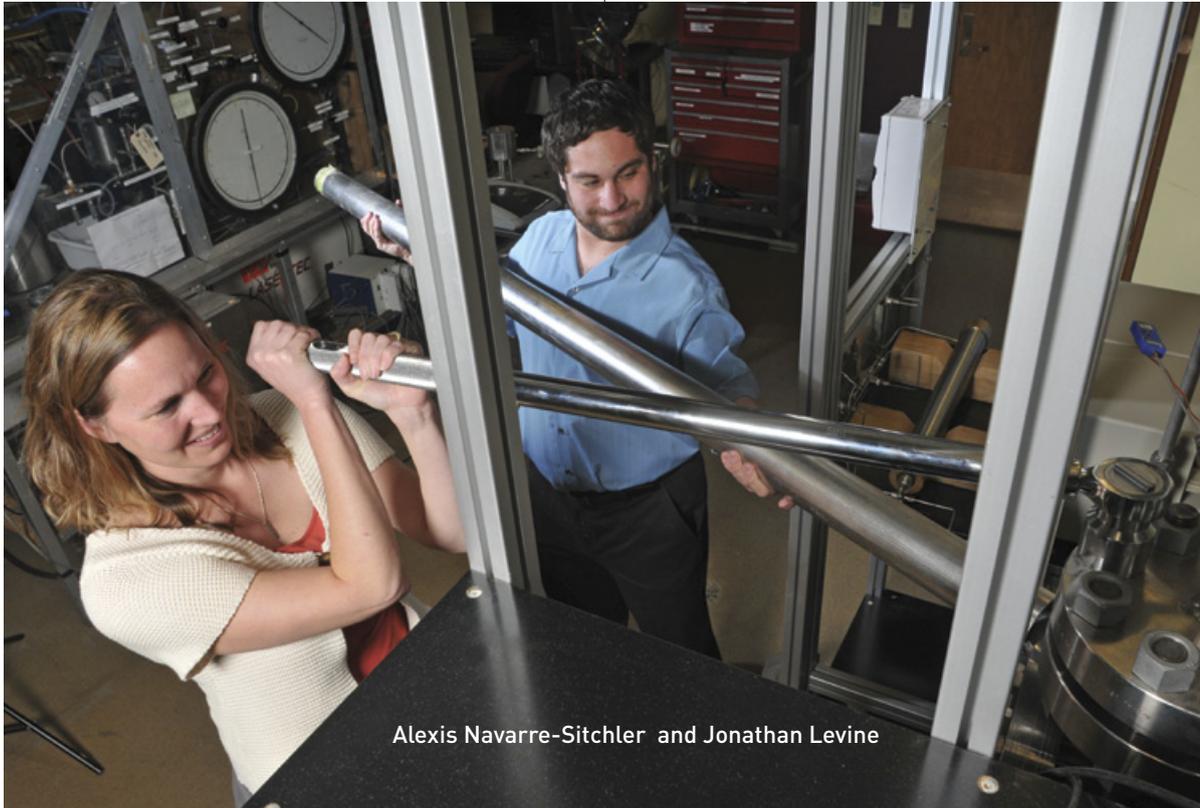
and in a simple package, such as a camera.

“This is by far the easiest circular micropolarizer to fabricate, which lets us measure all of the properties of light using a simple camera,” added ITN researcher Russell Hollingsworth.

Flammer and Hollingsworth, along with Mines physics researchers Katherine Bachman, Jonathan Peltzer, Reuben Collins and Tom Furtak, recently published these findings in “Spiral plasmonic nanoantennas as circular polarization transmission filters” in *Optics Express*, a journal of The Optical Society.

This work was made possible by a grant from the U.S. Air Force Office of Scientific Research.

Why not a carbon sequestration symposium?



Alexis Navarre-Sitchler and Jonathan Levine

Every weekday around the Mines campus, students conduct research in diverse topics related to carbon sequestration. On one designated day in January, they all got together.

Jonathan Levine and Alexis Navarre-Sitchler, two Mines researchers in the area of CO₂ sequestration, asked the question over coffee one day, “Why don’t we hold a campus-wide symposium?” That conversation led to the first Mines Student Research Symposium on Carbon Sequestration. For a full day at the Ben Parker Student Center, students and post-docs involved in different areas of this research topic shared their results with the Mines community through oral presentations and poster demonstrations. Carl Steefel from the Lawrence Berkeley National Laboratory delivered the luncheon keynote address.

Paying tribute to Levine, a post-doctoral scientist in chemical and biological engineering, and Navarre-Sitchler, a new assistant professor in geology and geological engineering, Dag Nummedal of the Colorado Energy Research Institute said, “At what was entirely their initiative, they organized a very successful symposium. It was well attended and the research was excellent.”

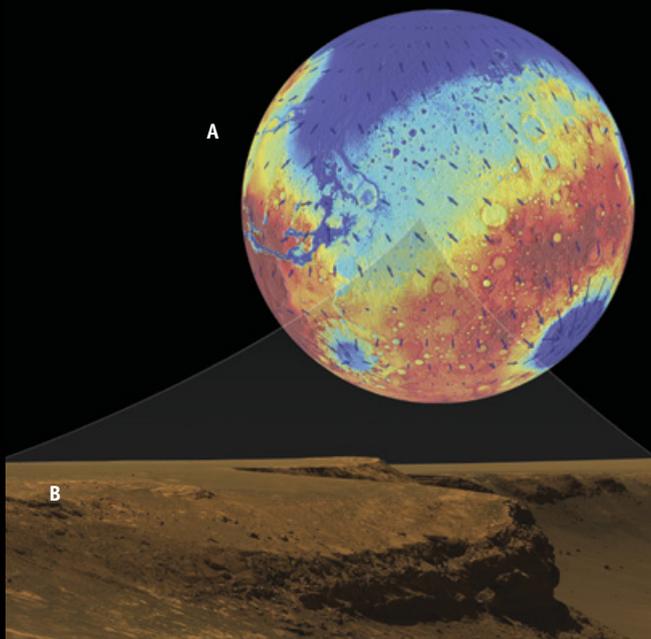
Co-organizer Levine collaborates with a team of scientists at the National Energy Technology Laboratory’s High Pressure

Water Tunnel Facility in Pittsburgh to study the formation of hydrates on gas bubbles at the pressures and temperatures found at the bottom of the ocean. The Mines Center for Hydrate Research now has a similar flow loop, which will be used to apply more than 35 years of research on the behavior of hydrates in pipelines to problems related to deepwater oil/gas blowouts.

“Hydrates plugged the caisson deployed during the Deepwater Horizon/Macondo leak that otherwise would have contained the leaking gas and oil in the first days of the disaster, avoiding much of the environmental damage,” explained Levine. “The aim of my research is to develop experimental data on hydrates for use by our industrial partners in the design of new containment equipment.”

Navarre-Sitchler’s research is centered on the geochemical reactions that occur when CO₂ is injected into rock formations. Her students perform laboratory experiments and use state-of-the-art characterization techniques to analyze chemical changes that rocks undergo at sequestration conditions. She also uses high-performance computing, including Oak Ridge National Laboratory’s Jaguar, one of the fastest computers in the world, to simulate CO₂ injection and reaction in heterogeneous rock formations.

Computer models tell watery Martian history



A: Theoretical patterns of groundwater flow superimposed over a Mars Orbiter Laser Altimeter (MOLA) topographic map of Mars, centered on Meridiani Planum.

B: Layered rocks containing evaporitic sulfate minerals in Cape Verde, Meridiani Planum, taken by the Mars Exploration Rover Opportunity (courtesy NASA/JPL/Cornell).

In 2001 NASA sent its Opportunity rover to Mars in search of evidence for water in the planet's past. The mission was successful, finding rocks containing salt that formed in a watery environment roughly 3.7 billion years ago, including the recent discovery of a rock nicknamed Homestake. However, knowing this area of the planet was wet in the past was only the beginning. In order to better understand the climate history of Mars, scientists wanted to know how the water got there and what made this part of the planet special.

This is where Mines Geophysics Professor Jeff Andrews-Hanna came into the picture. He used computer models of groundwater flow to understand Mars' watery past. His models were able to predict where these salty deposits formed and to explain what those rocks are telling us about the climate of Mars at the time. Now he and his group are using models of the climate and groundwater of Mars to understand a mound of sediments in Gale crater on Mars, the target of the Curiosity rover that is currently en route to the red planet.

The Chronicle of Higher Education (Feb. 5, 2012) quoted the lead investigator of the mission: "Jeff is really state-of-the-art right now," says Steven W. Squyres, a professor of astronomy at Cornell University and lead investigator of the Mars Opportunity rover mission, which found Homestake. "We use water on Mars as a sort of proxy for habitability, for evidence that the planet once could have sustained life, so it's really important," Mr. Squyres continues. "Jeff has brought a little physics into this work, and he is able to make predictions about water flow. We use those, in part, to guide our explorations. The rovers and the orbiters are the field geologists on Mars. Jeff is the theorist who brings their observations together."

The nature of early Mars' climate remains a controversial topic, as highlighted in a recent *Nature News* article featuring an interview with Andrews-Hanna. Debate continues between viewpoints of early Mars as a comparatively warm and wet place, or a cold and dry planet not very different from its present-day state. Research both at Mines and elsewhere will continue to push closer to an answer to this important question.

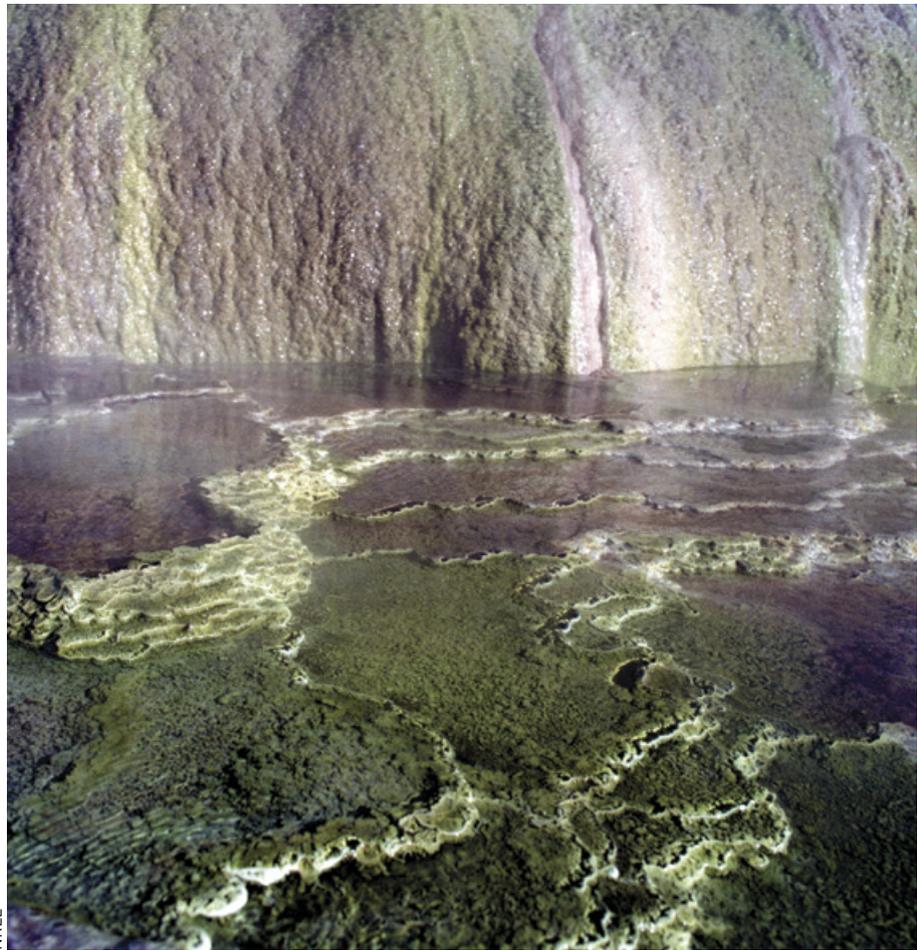
These days Andrews-Hanna has more help with those observations. His Planetary Geophysics Lab is attracting graduate students interested in researching the tectonic and geodynamic evolution of Mars, Martian groundwater flow, the crustal structure of Mars and the Moon, and the structure of the impact basins.

Discovering geothermal resources

U.S. Energy Secretary Steven Chu has announced two innovative projects at Mines, among 32 projects in 14 states, to receive funding to accelerate the development of promising geothermal energy technologies. They are:

- \$1.1 million for a project that will link reservoir temperature estimates with mineral analysis to aid discovery of unknown geothermal resources
- \$630,000 for a project that will develop an advanced processing framework for survey data to reduce the cost of geothermal exploration

“The Department of Energy is investing in pioneering new technologies that will further develop the nation’s geothermal resources, create skilled jobs for American workers, and help diversify our energy portfolio,” said Secretary Chu. “The projects announced today will provide opportunities for clean energy innovations that will ensure the U.S. remains a global leader in geothermal energy development and expand the nation’s use of this important renewable energy resource.”



NREL

African delegation tours water research facility



Water purification and sustainable water use planning were topics on the minds of a delegation from Africa during a recent visit that included a presentation, discussion and tour of the Advanced Water Technology Center (AQWATEC) at Mines.

Participants in the International Visitor Leadership Program, the delegation included visitors from six African nations including Burkina Faso, Djibouti, Mali, Mauritania, Niger and Senegal.

At AQWATEC, Tzahi Cath of the Department of Civil and Environmental Engineering described how sewage from the housing complex at Mines Park is pumped into a treatment facility in a small shed and purified.

Tissa Illangasekare receives European Geological Union's 2012 Darcy Medal



On the Mines campus, Tissa Illangasekare is known as the friendly, upbeat civil and environmental engineering professor who transformed the old Volk Gymnasium swimming pool into a state-of-the-art soil and climate wind tunnel. It's a snaking, wooden test facility where researchers study the transport of water from soil into the atmosphere, and other important problems, such as detection of buried land mines and leakage from sequestered CO₂.

But beyond campus — even across the world — Illangasekare is known for transforming the field of hydrology. That's why in April 2012 he received the Henry Darcy Medal from the European Geosciences Union (EGU), one of the highest honors of the field. He accepted the medal at the EGU General Assembly in Vienna, where he delivered the lecture “Let us keep observing and play in sand boxes.”

“I consider it a tremendous honor and achievement to receive this medal named after Henry Darcy, the renowned 19th century scientist, groundwater hydrologist and civil engineer,” said Illangasekare. “This medal not only recognizes my contributions to the hydrological sciences and water resources engineering, which was only possible with the help of many of my outstanding students, colleagues and collaborators in the U.S. and around the world, but it also recognizes my service to the hydrological community and society in general.”

Most hydrologists agree Illangasekare is the world's leading expert in non-aqueous phase liquid (NAPL) and multiphase flow in porous media.

“Illangasekare is the best experimentalist in the area,” according to the EGU announcement. “He is a leading expert in the integration of innovative experimental work with sound theoretical research. His work has continuously improved fundamental understanding of behavior and fate of non-aqueous phase liquids in heterogeneous porous media. Illangasekare has made pioneering contributions to quantifying mass transfer from entrapped NAPL sources of contamination to groundwater.”

These contributions not only improved science, they also had a direct impact on the lives of many people. In the wake of the Asian tsunami in 2004, Illangasekare raised funds to clean up wells and set up emergency sanitation systems in the affected areas. He also directed a National Science Foundation-funded team of experts who traveled to Sri Lanka to identify groundwater supply problems and support the clean up of wells.

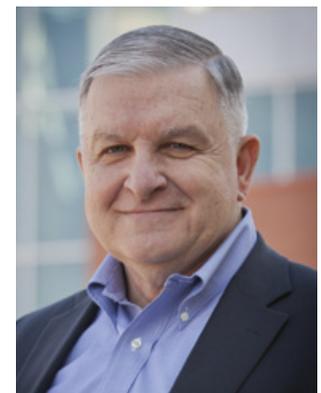
In his service at Mines, Illangasekare holds the AMAX Distinguished Chair of Civil and Environmental Engineering and is the founding director of the Center for Experimental Study of Subsurface Environmental Processes (CESEP).

Water Politics in the Middle East

Efficient water use, sustainable and cooperative management of water resources, desalination technology and population control are critical to the peaceful future of the Middle East, according to General Anthony Zinni, retired four-star general in the United States Marine Corps and former Commander in Chief of U.S. Central Command.

As one of the speakers in this year's guest lecture series sponsored by the Hennebach Program in the Humanities, Zinni spoke to Mines faculty and students about how water scarcity in the Middle East might affect relations between states that share an international river system. Since his retirement in 2000, Zinni continued to serve the country as the U.S. Peace Envoy in the Middle East.

Zinni co-authored Tom Clancy's book *Battle Ready*, released in 2004. His latest book, *Leading the Charge*, is based on his leadership experiences in the military and private industry.



Courtesy of Tonya Delborne

General Anthony Zinni

Consortium offers shale school for regulators and policymakers

Colorado School of Mines has joined Penn State University, the University of Texas at Austin, Exxon Mobil and GE in a training initiative to support the rapidly growing shale natural gas and oil development sector.

ExxonMobil and GE committed \$1 million each to the educational initiative.

The training programs created under the initiative will be led by the faculty at each academic institution and are designed to ensure that regulators and policymakers have access to the latest technology and operational expertise to assist in their oversight of shale development.

“Colorado School of Mines’ focused mission to educate the next generation of engineers and applied scientists fosters a natural partnership in this consortium. Our specialized curriculum and research program centered on responsible resource development is helping to enhance global understanding of our most pressing earth, energy and environmental challenges,” said Mines President Bill Scoggins.

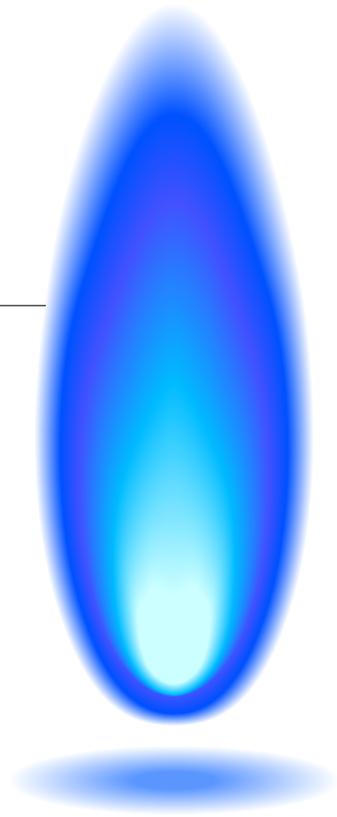
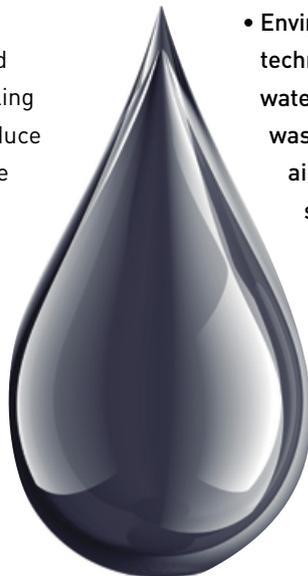
GE and ExxonMobil acknowledged hydraulic fracturing, horizontal drilling and other technologies used to produce shale resources are not new, but are being used on a larger scale than ever before — making access to scientific understanding of shale energy development important for regulators and policymakers.

“The Unconventional Natural Gas and Oil Institute at Colorado

School of Mines provides training for developing unconventional resources in an environmentally sound, safe and economically viable manner — the oil and gas industry as well as state and federal regulators and policymakers benefit from this expertise,” said Azra Tutuncu, who holds the Harry D. Campbell Chair in the Petroleum Engineering Department and is director of Mines’ Unconventional Natural Gas and Oil Institute.

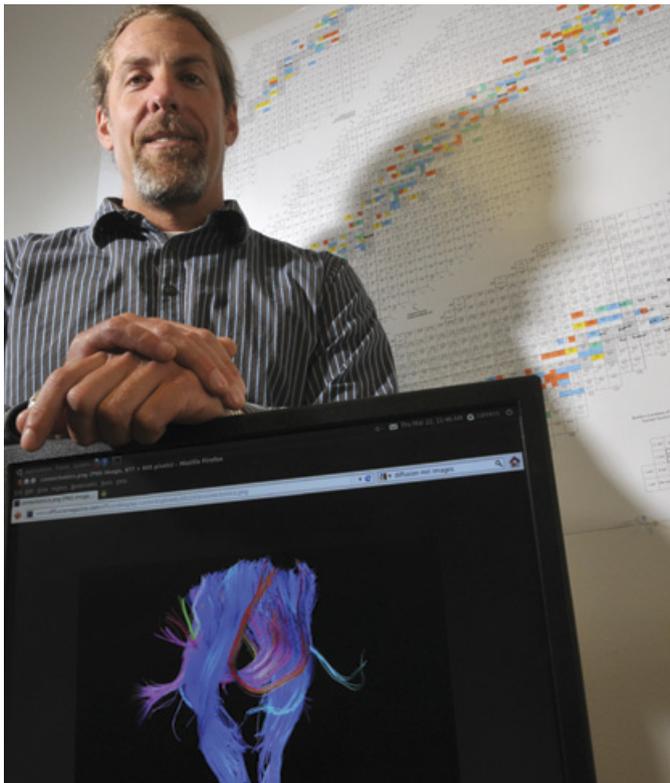
The courses, which will focus on the development of shale resources, will cover:

- **Petroleum geology, both conventional and nonconventional**
- **Petroleum technology, including principles of drilling operations and well design, as well as facility design and operation**
- **Environmental management technologies and practices, including water treatment and management, waste treatment and management, air emission control technologies, spill prevention, and planning and response**
 - **Federal and state oil and gas regulatory requirements, including permitting and reporting, plus compliance assessment**



ADDING TO A LONG LINE OF LEADERSHIP

New faculty members advance Mines' reputation for excellence



CORY AHRENS

Cory Ahrens, an assistant professor in the Department of Applied Mathematics and Statistics, is developing more accurate and faster ways to solve the radiation transport equation — the solutions to which could help researchers better model solar radiation transport through the atmosphere or electron penetration of a cancerous tumor during radiotherapy.

“By developing more accurate and efficient ways of solving the radiation transport equation, people can achieve a better understanding of global warming, design more effective radiotherapy cancer treatments and design safer and more efficient nuclear reactors,” Ahrens said.



ANNE SILVERMAN

Anne Silverman, assistant professor of mechanical engineering, specializes in musculoskeletal biomechanics aiming to improve mobility for people with disabilities.

“Improving mobility leads to a greater quality of life for the patient as well as greater productivity and reduced medical costs, which helps the overall community,” Silverman said. “As engineers, we have many tools that can largely impact rehabilitation.”

Using computer models, Silverman is getting a better understanding of how muscles contribute to movement and balance as well as energy costs and loads on joints. In her lab, she measures the human body’s motion to determine the walking challenges of those who are disabled.

“My work to date has focused on people with amputations between the knee and the ankle. To rehabilitate these patients effectively, we need to understand the function a prosthetic device should provide to achieve a given motion, as well as how the body interacts with and adapts to that device,” she said. “This knowledge will result in improved prosthetic designs as well as standardized goals for rehabilitation after amputation.”



ERIC TOBERER

Research conducted by Physics Assistant Professor Eric Toberer is focused on thermoelectric materials, a class of compounds that spontaneously develop a voltage in a temperature gradient.

“These materials can be thought of as solid state heat engines where electrons and holes are the working fluid,” he said. “These generators are critical for space missions where solar panels aren’t viable. For example, these generators will power the new Curiosity rover as it travels across the Martian surface.”

Toberer’s research aims to transition these devices to terrestrial applications, which could prove to be more economical than solar-thermal generators, as thermoelectric generators have no moving parts.

The Mines community’s dedication to understanding and improving materials for energy applications was a large draw for Toberer. He said the school’s focus on science, technology, engineering and mathematics also played a role in his decision to come here.

“It was clear that I would not be a lone principal investigator, but rather would be joining a community of scientists who are kept up at night by the same difficult questions,” he said.



YVETTE KUIPER

Yvette Kuiper, assistant professor in the Department of Geology and Geological Engineering, is a structural geologist.

“My research furthers our understanding of deformation processes of rocks and of plate tectonic movement and processes through time,” she said.

As part of her research, she is looking at the distribution of ore deposits in various tectonic settings, which are commonly controlled by faults and folds. She also is a geochronologist and uses radiometric methods to date minerals in rocks to date the deformation with which their growth is associated.

Kuiper’s National Science Foundation CAREER award research, “Exhumation of a high-grade metamorphic terrane, and late-stage orogenic collapse in the southeastern New England Appalachians,” focuses on the structural history of that mountain range with an emphasis on the collapse of the mountain belt during or after its formation. Her research is strongly field-based and will incorporate the work of Mines students of all levels.

VENTURING INTO THE MARKETPLACE

Historically, Colorado School of Mines has been a leader in energy research and technology development. While that fact holds true, some of today's researchers are forging new frontiers in areas not usually associated with Mines, including biomedicine.

For example, Physics Professor Jeff Squier holds one of the original patents for femtosecond LASIK eye surgery and continues to advance that technology with a focus on surgeries requiring a high degree of precision with respect to cuts made close to sensitive membranes.

Across campus, Will Fleckenstein, an adjunct professor in the Petroleum Engineering Department, is working on improving hydraulic fracturing technologies to increase productivity of natural gas wells.

"The inventions the technology transfer office receives from faculty and students cover a wide breadth and tend to be more applied than most university inventions, which helps facilitate their movement into the marketplace," said Will Vaughan, director of Mines' technology transfer office.

"We've been working to open several avenues for the commercialization of the inventions while keeping the academic mission first and foremost. There have been some notable successes and we will continue to enhance the entrepreneurial culture as we move forward," he said.

ENCOURAGING ENTREPRENEURSHIP

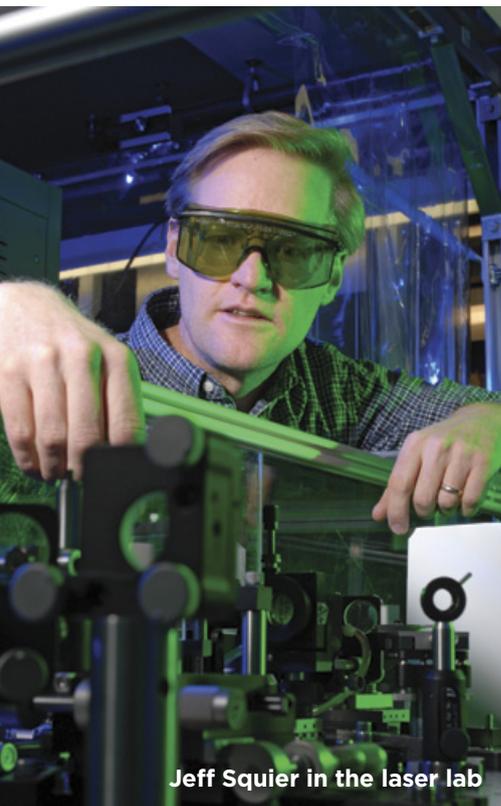
As part of an initiative to encourage entrepreneurship within the Mines research community, a fund aimed at bringing technology to the commercial marketplace was funded by the Colorado School of Mines Foundation under the leadership of the Foundation Board of Directors Chairman David Wagner.

The Colorado School of Mines Proof of Concept Fund — \$350,000 over a three-year period — will allow several research projects to head down the commercial pathway. The intent is to license the technologies to private companies or serve as the basis for start-up companies.

Chemistry Professor Kent Voorhees' project, "Next Generation Point-of-Need Analyte Detection and Identification using Novel Lateral Flow Capillary Concentration and SERS," is a method for detecting bacteria such as *Listeria*.

"The original iteration of this technology was patented by Mines and later licensed to Microphage, Inc. for use as a rapid method for detection of methicillin resistant *Staphylococcus aureus* (MRSA) in hospitals," Voorhees said.

The system is being distributed internationally as the first phage-based bacterial detection device for clinical MRSA screening and is the only FDA-approved MRSA detection device. It is being adopted by some of the largest hospitals in the U.S.



Jeff Squier in the laser lab



Voorhees said his team has continued to refine the technology and has applied the improvements to detection of various pathogens and bacterial agents of biowarfare including plague, anthrax and food borne E-coli. It also has the potential to target viruses, fungi, hormones and cancer markers.

Hongjun Liang, an assistant professor in the George S. Ansell Department of Metallurgical and Materials Engineering, also received funding for his project “Development of Artificial ‘Cells’ for Anti-Cancer Drug Delivery,” a method for delivering a variety of anti-cancer drugs.

Also funded was Adele Tamboli, research assistant professor in the Department of Physics, for her project “Electrochemical Extraction of Sodium from Silicon Clathrates,” which examines modifications of structures to store hydrogen and other atoms.

The material, silicon in the clathrate crystal structure, is an exciting topic

with the potential for a lot of renewable energy applications. Researchers at Mines are among only a few groups synthesizing this material.

“This project is a patentable component of the research that could enable a number of renewable energy applications, such as hydrogen storage materials and photovoltaics, that could form the basis of start-up companies,” said Tamboli.

ENTREPRENEURIAL EXPERIENCE FOR UNDERGRADS

Entrepreneurship at Mines extends beyond the faculty research corridors. Graduate courses focused on the subject have been offered for several years through the Division of Economics and Business Engineering and Technology Management Program, but as of fall semester 2011, undergraduate students also are learning what is involved in

taking an idea to the marketplace.

“What better place than Mines?” Joy Godesiaboib, a teaching associate professor in the Division of Economics and Business, remembered thinking when setting out to teach the university’s first undergraduate class focused on entrepreneurship.

Godesiaboib taught a similar course at another Colorado university, where students brainstormed ideas for T-shirt stores, heli-skiing businesses and bars — but at Mines, students were talking about developing tools to detect blood sugar levels for diabetics and selling used oil drilling equipment to developing countries.

“I was blown away,” she said. “These students are so creative; they get such amazing training in their individual areas here at Mines. They come into entrepreneurship class with ideas that can be game changers.”

The entrepreneurship class gives students a different viewpoint, a different way to look at a problem. Not only are students learning leadership skills and gaining self-confidence, they are forced to face a problem that doesn’t have one correct answer — there is no formula.

“When comparing the students on the first day of class with the last day of class, you can see the changes in how they are thinking about things,” she said.

They learn management skills, how to work independently, how to work and function within a group and how to develop a financial plan. Going into the business world after graduation versed in risk and profitability gives engineering students an edge in talking with management in business terms, Godesiaboib said.

Students were so enthusiastic about the class, they started an Entrepreneurship Club. The club works as a networking tool for the students as well as a practice vehicle for what they are learning in class.

FROM LAB TO SOLAR LEADER

The story of Colorado School of Mines, NREL and PrimeStar



October 2011 was an exciting month, not only for Mines, the National Renewable Energy Lab (NREL) and the state of Colorado, but for solar energy in general. Coming off the purchase of Colorado-based PrimeStar Solar, Inc., General Electric (GE) announced it would build a \$300 million photovoltaic (PV) production plant in Aurora, Colo. — the largest of its kind in the U.S.

It was a mix of institutions, knowledge and bright people that brought GE into the solar industry with such an investment. The backstory begins in 1996 with a Mines graduate student named Joe Beach, who is now a Mines research professor.

“The reason I came to Mines was because I was looking for ways to get into renewable energy,” said Beach. “At that time Mines was one of the few places that actually talked about it.”

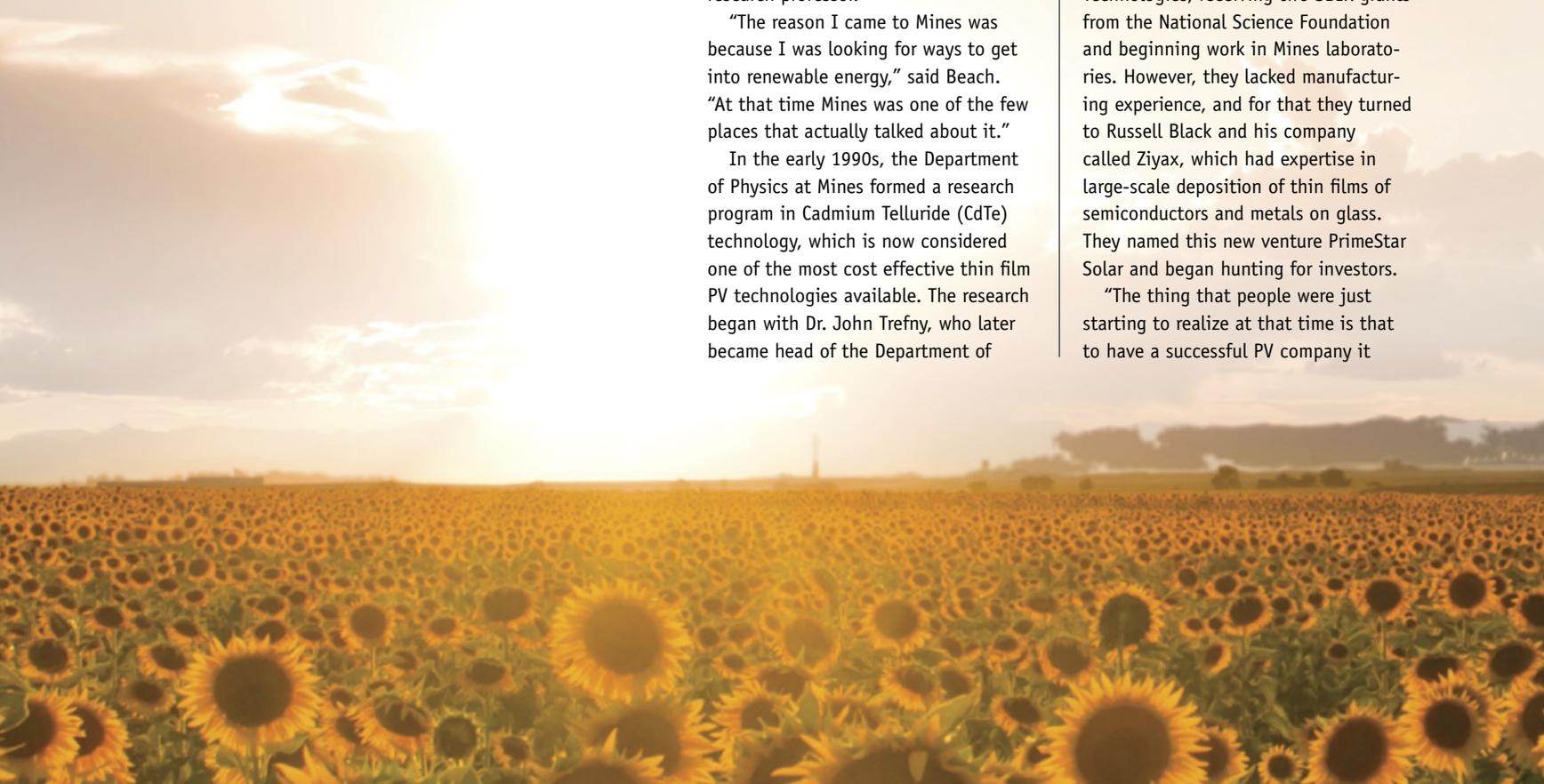
In the early 1990s, the Department of Physics at Mines formed a research program in Cadmium Telluride (CdTe) technology, which is now considered one of the most cost effective thin film PV technologies available. The research began with Dr. John Trefny, who later became head of the Department of

Physics and then president of the university. That research was funded by the Thin Film Photovoltaic Partnership Program, which was managed by NREL. By the time Beach started work on the program, shortly after earning his PhD, leadership had been handed off to Associate Professor Tim Ohno. It was in working with Ohno that Beach met graduate student Fred Seymour.

“I had an interest in moving laboratory research into commercial work and it turns out Fred Seymour did too,” said Beach.

Seymour and Beach collaborated to form a small business called PV Technologies, receiving two SBIR grants from the National Science Foundation and beginning work in Mines laboratories. However, they lacked manufacturing experience, and for that they turned to Russell Black and his company called Ziyax, which had expertise in large-scale deposition of thin films of semiconductors and metals on glass. They named this new venture PrimeStar Solar and began hunting for investors.

“The thing that people were just starting to realize at that time is that to have a successful PV company it



takes between \$500 million and \$1 billion in investment,” said Beach.

GE was interested in investing in the solar market, having shopped for opportunities at other institutions in Colorado. Ultimately, however, GE approached PrimeStar and became the largest investor before purchasing the company in April 2011 and announcing its plans to ramp up production with the construction of the largest PV manufacturing plant in the U.S. PrimeStar Solar is now part of GE, and Fred Seymour is general manager of Solar Technology for GE Energy – Renewables.

“The big thing that the research here at Mines did for PrimeStar is it produced people with excellent technical skills,” said Beach, who added that the company licensed its patents from NREL, which has been active in CdTe research since the early 1980s. “You’ve got to have the right combination of engineering expertise, science expertise, entrepreneurial interest and willingness to just doggedly pursue a problem. It will make or break the transition from a laboratory technology to something that is viable commercially.”

In isolation this is a success story, yet much of the U.S. solar industry is struggling. First Solar reported its first losing quarter at the end of 2011, while Abound Solar halted production of its first-generation panel and cut roughly 180 jobs at its Loveland, Colo., facilities. California-based Solyndra filed

for bankruptcy and shut its doors after receiving more than \$500 million in federal government loans.

At the macro level, however, there are economic challenges at play.

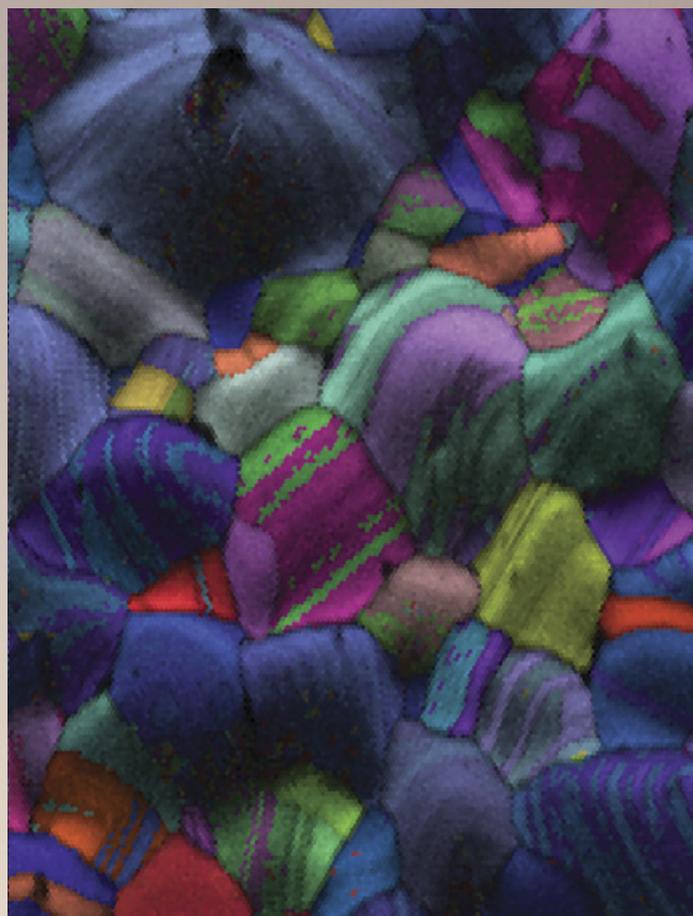
“The overall PV industry problems are due to a 50 percent overcapacity right now,” said Beach. “There really isn’t a barrier to entry in the market.”

Debate continues on whether China presents unfair competition. Chinese manufacturers get extremely cheap loans and do not pay income taxes. This gives them a significant cost advantage without requiring any technology advantage, and has caused resentment and charges of dumping by some other PV manufacturers. Taking cues from the history of foreign car manufacturers in the U.S., Chinese PV companies began building assembly plants in their sales markets. This reduces shipping and working capital costs and creates manufacturing jobs in the sales markets.

Further increasing the complexity of the issue, struggling American photovoltaic start-up companies, such as Ascent Solar (another Colorado company with ties to Mines), have been supported financially by investment from Chinese firms.

Much is to be determined in the photovoltaic energy game and, as it has in the past, Mines will play a leadership role moving forward.

We are clearly at a challenging time in the PV world,” said John Poate, vice president for research and technology



Electron backscatter diffraction image of polycrystalline cadmium telluride (CdTe) film on a glass substrate. A false color enhancement is used to identify grain orientation — i.e. the different ways in which atoms are aligned within the film. This is the material that forms the basis for PrimeStar’s photovoltaic technology.

transfer at Mines. “The modern PV cell was invented at Bell Labs in 1954. CdTe is another pioneering U.S. technology. It is essential that we compete successfully in this industry, which we invented. To do this we will need a coherent national strategy to stay ahead of the game.”



ETHICS, HONESTLY

The hallway was empty when Professor Roel Snieder approached. “No Class Today” the sign on the door announced. But it wasn’t true. Snieder had not cancelled class. “Steam was coming out of my ears,” said Snieder, co-director of Mines’ Ethics Across Campus (EAC) program.

A few moments later two late-arriving students appeared. “Since no one is here,” one asked, “would you give us some advice on a project we’re doing?” Not wanting to waste the hour, the still seething Snieder agreed and followed them into a classroom. “April Fool!” yelled the laughing students from the not-really-cancelled class. Snieder laughed a little too, but the

nervous students quickly got serious. It was clear that honesty isn’t something Snieder is comfortable joking about – even on April 1.

EAC encompasses many ethics-related educational, research and outreach activities. Consistent with Mines’ mission statement and its goals for undergraduate and graduate students, ABET (the engineering accreditation agency) criteria, and National Institutes of Health and National Science Foundation requirements, EAC promotes responsible and ethical conduct.

Mines has always stood for integrity, of course, but in an increasingly complex world, ethics reflection and research have expanded and become

more formalized.

As Snieder, who holds the Keck Foundation Endowed Chair of Basic Exploration Science, has noted: “Science and engineering in the broadest sense not only help us better understand the world in which we live; these fields also increase the power that we hold over the world. Unfortunately, neither science nor engineering comes with a recipe for how to use that power.”

Undergraduate courses under the EAC umbrella include Nature and Human Values, Environmental Ethics, and Engineering and Social Justice, all delivered by the Division of Liberal Arts and International Studies (LAIS). Students in the LAIS basic general ethics course get practical experience each spring selecting a winner for the Golden Rotary Club “Ethics in Business Award.” And LAIS faculty working with Metallurgical and Materials Engineering Professor Corinne Packard recently secured a new NSF grant to infuse modules on the ethics of nanotechnology into the undergraduate LAIS curriculum.

Graduate courses include The Art of Science and Introduction to Research Ethics, which is team-taught by a faculty member from LAIS and another from applied science and engineering. And since 2010, LAIS Assistant Professor Jason Delborne has taken a small group of Mines graduate students to “Science Outside the Lab,” a policy immersion program in Washington D.C.

LAIS Professor Carl Mitcham,

10 ETHICS QUESTIONS FOR THE SCIENTIST OR ENGINEER

By Roel Snieder, Mines professor

What do I value?

What do I want to grow?

Who, or what, do I serve with my work?

What is the noble purpose of my work?

What types of errors are ethically acceptable?

Why is trust so essential in science?

Why does plagiarism constitute an ethical problem?

Why file for a patent?

Who should be among the authors of a paper?

Who should be first author?

PERSONAL CODE OF PROFESSIONAL ETHICS

By Dan Worrall, Mines graduate student

Honest Conduct: Never falsify data; never lie; never give a mostly true, easy answer instead of a difficult, fully true answer. Present contradictory evidence if it exists. Finally, never present others' work as my own.

Keep Quality Records: Keep clear and thorough records. This will help me to produce better quality research, prevent me from making and publishing unknown errors, and make the results generated more useful to others.

Publicize Research: Publish as much data as possible. Share results as well as detailed methodology. Always be willing to help those who ask.

Mentor Others: Make it a professional priority to help develop other engineers, and never hold back skills or discoveries for personal gain.

Practice Discretion: Refrain from arguing points I am not thoroughly knowledgeable of. Never present a statement as fact when I am not fully aware of the supporting data.

Be Aware of Wider Impacts: Always keep in mind the effects of my work on other people and society at large.

Separate Goals and Ethics: Always keep in mind what my personal goals are and how they may cloud my judgment. A decision may advance my career and still be ethical, but care must be taken to keep personal desires out of ethical reasoning.

Evangelize: Try to let my behavior be a good example of ethical professionalism, and try to promote openness and collaboration in research.

Blow the Whistle: If a superior is acting in an unethical manner, it is my responsibility to confront and/or report him or her.

EAC co-director and director of the Hennebach Program in the Humanities, regularly serves as one instructor in the team-taught Research Ethics seminar. As Mitcham explains, pedagogical research has shown that the effectiveness of such a class depends on an interdisciplinary approach and interaction among participants. Working together, faculty and students collaborate to:

- Compare, contrast and evaluate basic ethical theories
- Address a range of real-world ethical issues they may confront in their professional lives
- Articulate their own ethical ideals and commitments to science, society and the environment

Mitcham and Snieder are repeatedly impressed by the depth of thought and conviction that students reveal in the personal ethics statements that cap their seminars. They don't grade the specific ethical perspective students develop, but rather look for the quality of argumentation and materials the students use to support their positions. The process is inspiring. "Their seriousness encourages me to try to lead a more serious life as well," said Mitcham.

Mitcham is, indeed, serious about the field of ethics. He has edited a four-volume *Encyclopedia of Science, Technology, and Ethics* (2005), which will come out in a second edition next

year. As an expert for the European Commission's Directorate-General for Research and Innovation, Mitcham is also the editor of a report, "Ethical and Regulatory Challenges to Science and Research Policy at the Global Level." This report's proposal for the promotion of global standards for responsible research and innovation has been endorsed by the Danish presidency of the European Union, which recently sponsored an international conference

on "Science in Dialogue: Toward a European Model for Responsible Research and Innovation." Mitcham was an invited participant.

As Mitcham and co-author Adam Briggie argue in *Ethics and Science*, forthcoming from Cambridge University Press, "The kind of world we are creating will not simply be decided by expanding scientific knowledge, but will depend on views about good and bad, right and wrong."

LEADERSHIP THROUGH INITIATIVE

UNDERGRADUATE RESEARCH

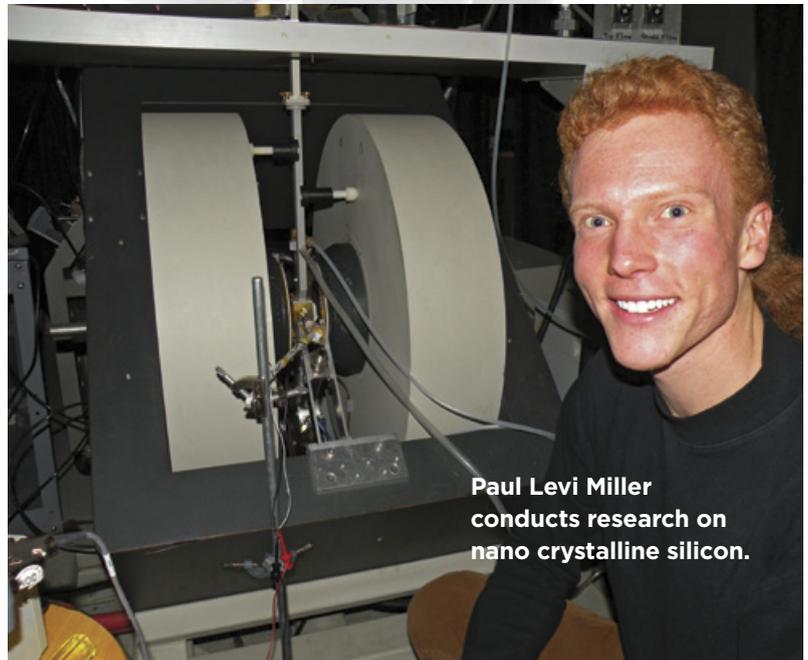
Sit down and talk with Mines undergraduate student Paul Levi Miller and you will notice right away he is very enthusiastic about science.

"I like science a lot, but I also like science that can help people," said Miller, a senior engineering physics major. "Renewable energy will solve a lot of our problems at a very fundamental level."

As an undergrad, Miller is working directly on game changing research. Together with Physics Professor Reuben Collins, he studies nano crystalline silicon, a material of particular interest to scientists for its potential to improve solar cell efficiency by preventing energy from being wasted to heat "just by taking advantage of energy that is already interacting with these materials."

Miller's research began when he was a sophomore and participated in a National Science Foundation funded Research Experience for Undergraduates (REU) program at Mines' Renewable Energy Materials Research Science and Engineering Center (REMRSEC). It was a 10-week summer session allowing him to direct his own research project for the first time.

"I started from not really knowing how research worked to actually



Paul Levi Miller conducts research on nano crystalline silicon.

becoming a researcher who is pretty self-sufficient, who could come up with questions and figure out ways to answer them. And that's really what research is all about," he said.

The experience was a springboard to other opportunities, approaching professors to participate in their research projects and even working on a paper currently under review to be published in *Nature*.

Miller's experience underscores an aspect of the institutional culture of

Mines where professors and research projects are accessible and an undergraduate's experience can be determined simply by initiative and desire to get involved in ongoing scientific study.

Miller said his research experience put him in a different league when applying to graduate schools — he was accepted to all four of the schools to which he applied. He plans to attend the University of California, Santa Barbara.

GRADUATE LEADERSHIP ON A NATIONAL SCALE

In the lobby of the Green Center at Mines, a graduate student described fatigue tests for wind turbine blades while pointing at a large poster filled with colorful diagrams. Nearby another student explained carbon isotope chemostratigraphy of the Niobrara Shale formation. Another analyzed the geochemistry of a volcanic hydrothermal system at Mount Spurr, Alaska.

Held in March, the occasion was the 2012 Conference on Earth Energy Research (CEER), one of the largest events sponsored by the Colorado School of Mines Graduate Student Association (GSA).

"As graduate students, one of the things we're really focused on is making sure the novel ideas and research we work on are discussed collaboratively in the public domain," said Chemical Engineering graduate student Zach Aman, president of the GSA, co-coordinator of CEER and a recent recipient of a Best Student Poster Award at the Gordon Research Conference on Natural Gas Hydrate Systems.

CEER brought in more than 160 participants from around the nation to share new ideas on earth and energy issues. Eighty judges, comprised of faculty, alumni and industry representatives, judged the presentations in real-time using custom-designed software on an iPad or laptop — a first for graduate research conferences in the U.S.

The judges evaluated not only scientific merit, but also how well the grad students communicated their work.

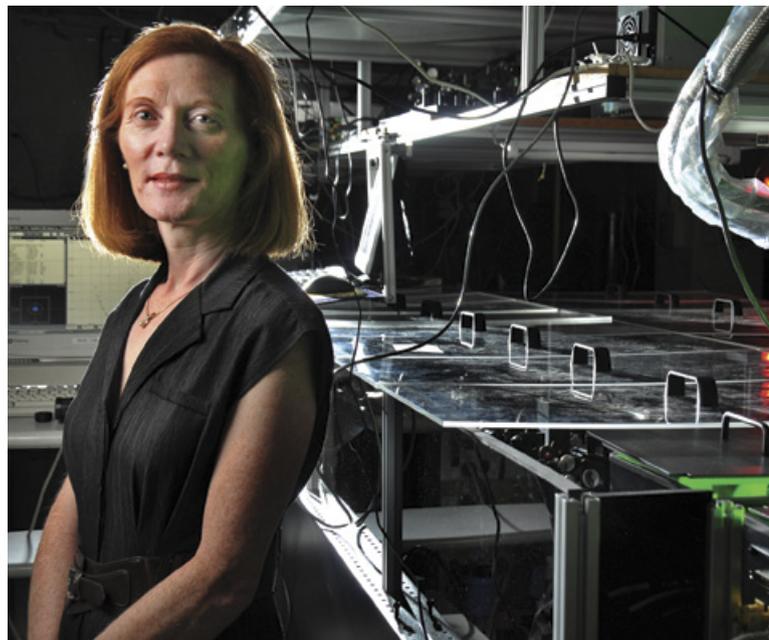
"It's about understanding your audience, communicating at the level of your audience, and being able to discuss your research regardless who

you're talking to," said Cerica Martinez, vice president of the GSA and CEER conference chair.

CEER presents just one example of the bold leadership of Mines graduate students. Mines' GSA continues to set standards for graduate student associations nationally — it is one of the most independent, well-funded graduate student groups in the nation. This allows the group to offer travel grants for students to attend conferences, bring interdisciplinary lectures to campus and assist graduate students who have lost funding. Through a partnership with

the Colorado School of Mines Alumni Association, GSA's graduate continuance fellowship provides \$5,000 in tuition and \$4,000 in living expense assistance. It's a first of its kind in the U.S.

"We are very proud of the fact that, as compared to many universities around the country, the GSA at Mines gets tremendous support from both the students and the faculty. We have a very strong and well defined graduate structure," said Aman. "Because of this, we are able to offer innovative, cutting-edge programs to address the needs of this graduate population."



Glenn Asakawa/University of Colorado

Dr. Margaret Murnane, an award winning physicist and world-renowned expert in ultrafast lasers, delivered the keynote address at the 2012 Conference on Earth Energy Research. Murnane serves on President Barack Obama's Committee of the National Medal of Science. She also serves as a fellow of the Joint Institute for Laboratory Astrophysics (JILA) and as a distinguished professor in the Department of Physics at the University of Colorado at Boulder.



MEDIA CITE MINES IN STORY AFTER STORY

“Bi-fuel Cars May Be Future of Auto Industry”
KUSA-TV 9News, May 3, 2012

“Best Returns on College Investment – How Schools Rank”
Investor’s Business Daily, April 27, 2012

“Gold Glitters for North American Mining Students”
Thomson Reuters, April 15, 2012

“Jobs Abound in Energy Industry’s New Boom Time”
NPR, March 12, 2012

“Mines to Get Money to Expand Shale Regulation Teaching”
Denver Business Journal, March 8, 2012

“Water Tunnels Would Be Huge Project – If They Clear Huge Obstacles”
Sacramento Bee, Feb. 20, 2012

“Recreating Mars as a Watery World”
The Chronicle of Higher Education, Feb. 5, 2012

NEWS

“Report Backs Greater Use of Recycled Wastewater”

Los Angeles Times, Jan. 11, 2012

“Report: Wastewater Preferable to Wasting Water”

USA TODAY, Jan. 10, 2012

“Cheap Schools That Pack an ROI Punch”

Business Week, Jan. 9, 2012

“Colorado Takes the Lead in Fracking Regulation”

Fox News, Jan. 5, 2012

“Billions of Barrels of Oil Possible Under Colorado”

CBS Denver Channel 4, Jan. 3, 2012

“Game Changers, Water Works, Jörg Drewes”

5280 The Denver Magazine, December 2011

“Santiago’s Brain”

Rolling Stone, Dec. 8, 2011

“Could You Be a \$200,000-a-Year Miner?”

The Wall Street Journal, Nov. 18, 2011

“Pitfalls on the Road to Tapping New Energy”

New York Times, Nov. 15, 2011

“Urban Water Infrastructure”

U.S. News & World Report, Nov. 11, 2011

“Colorado’s Longtime Economic Development Efforts Start to Pay Off”

The Denver Post, Oct. 16, 2011

“Colorado Lands GE Solar Plant”

Denver Business Journal, Oct. 13, 2011

“Educational Experiences That Changed a Life”

New York Times Magazine, Sept. 18, 2011

“Colleges That Help Grads Get Top Salaries”

SmartMoney Magazine, Aug. 11, 2011

“Colorado Has Rich History with Space Shuttle Program”

The Denver Post, July 10, 2011

INTERVIEW

TRULY A LEADER



Retired as a vice admiral after a Navy career of 30 years, Richard Truly can speak about leadership from a remarkable perspective. He began his career after earning a degree in aerospace engineering from Georgia Institute of Technology. After distinguished service as a naval aviator, Admiral Truly became one of the first military astronauts. He piloted the Space Shuttle Columbia and was commander of the Space Shuttle Challenger. He left NASA to become the first commander of the Naval Space Command. Called back to NASA, Admiral Truly led the accident investigation and rebuilding of the space shuttle program following the Challenger accident, then served as the eighth administrator of NASA.

Later Admiral Truly served as vice president of the Georgia Institute of Technology and director of the Georgia Tech Research Institute and then as director of the Department of Energy's National Renewable Energy Laboratory (NREL). He is a member of the National Academy of Engineering. In addition to numerous professional awards, recognitions from NASA and many military decorations, Admiral Truly was awarded the Presidential Citizen's Medal by President Ronald Reagan. He serves on many boards, including the Colorado School of Mines Board of Trustees as vice chairman.

John Poate, vice president of research and technology transfer at Mines, interviewed Admiral Truly in the lobby of Maple Hall on the Mines campus.

DR. POATE: It's a pleasure to have you here. As you know, we're going to be talking about leadership. I'd like to hear a few vignettes of your storied career. For example, what was the most challenging?

ADMIRAL TRULY: First of all, let me thank you for the opportunity to sit down and talk for a bit. I've been an admirer of Colorado School of Mines for as long as I can remember. And to be a trustee here is a real privilege. I've had a lot of challenging opportunities. Probably the first one was staying alive in my first Navy squadron. I didn't have much flying time. We were flying day and night off a modernized World War II aircraft carrier. Then we went to the U.S.S. Enterprise, which is the first nuclear carrier. So that was an accomplishment I appreciated.

DR. POATE: Staying alive?

ADMIRAL TRULY: Yes! And then I went down to NASA as an astronaut and got to be in the shuttle program, which was really fun because we were there in the early days before it ever flew. We designed the cockpit. We designed the displays. We were, from an engineering point of view, knee-deep in that vehicle. But by far



the most challenging professional thing I've ever done was the Challenger experience. I had left the astronaut office a couple years before. I flew the Enterprise off the top of the 747. Then I flew the second flight on Columbia. Then I commanded a night flight on Challenger. But my family and I were burned out frankly. And I was burned out — not from flying, but from sitting in the stupid simulator all the time. I was still in the Navy. The Chief of Naval Operations Jim Watkins and the Secretary of the Navy John Lehman were starting a new Naval Marine Corps Space Command. So I left Houston and was at that command at the time of the Challenger explosion.

DR. POATE: How many of the crew on the Challenger did you know personally?

ADMIRAL TRULY:

I knew them all. A couple of them were

dear friends. To understand the problem that I was going to face, although I didn't know it: In the year before the Challenger accident in 1985, huge pressures with the shuttle program had built up. NASA had flown over 20 flights and made it look easy. And it's not easy. NASA headquarters was pushing to keep the flights on schedule. They were signing up commercial payloads. But to operate the shuttle was not any easier on the 20th flight than it had been earlier.

The second thing that was going on was political. The NASA administrator in 1985 was indicted — from the time when he had been an executive at an aerospace company. Let me be quick to point out that he was eventually exonerated. Nevertheless, he was the sitting NASA administrator and was indicted by the federal government. And so he resigned. NASA did not have an administrator. And on the 28th of January 1986, the wheels came off. The Challenger exploded.

In that week the Rogers Commission was formed. Bill Rogers was the chairman — a former secretary of state. Neil Armstrong was the vice chairman, and there were several other well known names on the commission — Chuck Yeager, Sally Ride, Richard Feynman. It was quite a list of people. I, of course,

was still at the Naval Space Command. Well, I began getting phone calls about going back to NASA, and I had never intended to — I had left NASA for good. Finally one evening about two weeks later, the Secretary of the Navy John Lehman called me, and within two days that was followed by a call from the White House. I was pulled out of that command and in two more days, I walked into NASA headquarters.

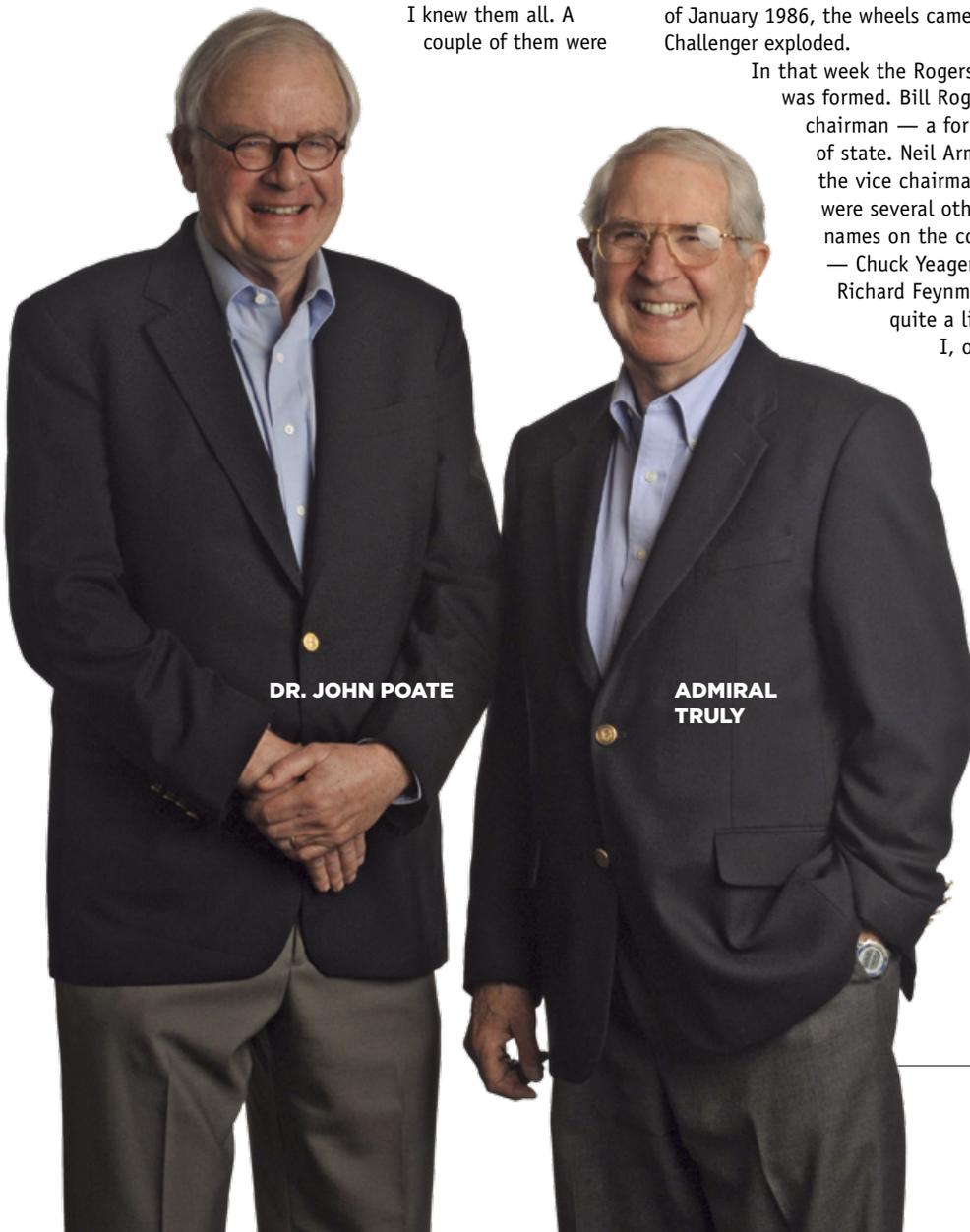
I have never seen a disastrous situation like that in my life. When I walked into the floor where my office was, there were literally people crying in the corridor because of the pounding they had been taking in the media. By that time, rather than an airplane accident, it was 'NASA has killed its crew.' It was the start of the most tumultuous engineering, political, cultural, social endeavor that I've ever found myself in. I was responsible for the investigation itself, working for the Rogers Commission. At the same time I was responsible for the return to flying. I had never been to a Congressional hearing in my life, and I testified at about 25 in the next three months. So it was — you asked about challenges — I was up to here in challenges.

DR. POATE: Feynman. What impression did he make on you? To physicists, he is one of the heroes of the 20th century.

ADMIRAL TRULY: The thing that I found fascinating about him was that outside of the formal investigation — and outside even of the subject of the accident — he was the most entertaining person to talk to that I can imagine. And when the Rogers Commission eventually wrote their report, he wrote his own report. It is an appendix of that investigation. If you read it, it's more like a thought piece. It's question after question he didn't think was answered well by NASA.

DR. POATE: You played a historic role there in the commission. With your background in NASA — and understanding space flight and its importance to us — what are your thoughts regarding the future of manned spaceflight and extra-planetary exploration?

ADMIRAL TRULY: Wouldn't it be fantastic if the commercial sector could build spacecraft that were safe enough, reliable enough, and could fly humans into space? That would be a marvelous thing, and it's something that I



DR. JOHN POATE

ADMIRAL TRULY



would support. I've been in the middle of that business, and doing it once is great. Doing it twice is great. But you have to do it again and again and again and again — safely, within cost and a decent schedule. And I am skeptical because we have now shut down our capability to take humans into space. We're like at the bi-plane era of the Postal Service when it comes to commercial achievement.

I think we should be exploring. I don't think we'll ever have another program like Apollo. Apollo was a magic program in a decade where nothing else good was going on. But I believe we should be shooting to go back to the moon. Just because we've touched it doesn't mean we've explored it. And then eventually the only other planet we humans can land on is Mars. But we just had a program that was to go back to the moon and then on to Mars, and we cancelled it. That blows my mind.

To have a space program that succeeds, it's got to succeed through multiple presidents and many multiple Congresses. Therefore it can't be a Democratic program. It can't be a Republican program. It's got to be an American program.

DR. POATE: A very important part of your life was when you headed NREL. You were critical in the success of that lab. So with your understanding of the whole renewable energy game, give us your thoughts on our energy policy and where we're going. I know that you were on a panel — probably chaired it — on the security implications of global warming.

ADMIRAL TRULY: The National Renewable Energy Lab, NREL, is a neighbor of Mines, and it was a fantastic opportunity to be over there, and it moved me to Colorado, which I'm not going to correct. And while I was at NREL, I looked around for a university that had the same DNA, and it's right here at Colorado School of Mines.

Despite all the noise you hear from the renewable community, or the nuclear community, or the oil and gas community, I do think we have begun a transition to an energy future that is different than the one we've known. And therefore it's exciting. It's hugely important. And Colorado School of Mines is right dead in the middle of it. Where is it probably going to go? It's probably going to have large swings. You can just look at the NREL budget, and it looks like a bouncing ball. Look what's going on with nuclear. Before the

Japanese tsunami accident, there really were a lot of national voices saying, "Nuclear's coming back." Now it's pretty silent. It'll probably come back again.

I do think there are strong connections between national security and climate change. The specific study that you asked about actually was a study about fuel efficiency and weapons platforms — air, sea and land. And it was fascinating. When we went into the study, I thought it was going to be all about technology — new turbines and sleeker aerodynamic shapes. It turned out that, even though technology has an important role to play, it's really about the culture. It's about the culture of the Pentagon, and the Secretary of Defense's office and the services, because they do not care about energy efficiency for its own sake. That's not their business. What they do care about, though, is if they could have an airplane that could go a third longer range on the same fuel load. What they have finally learned — in spades — is what it means to fight a war in a faraway place where you're so dependent on long lines of fuel trucks that you have to guard with helicopters and soldiers. If you could run your operation with a third fewer fuel trucks, it'll change the game.

DR. POATE: Across the world, public universities are being challenged by lack of support by their communities at state and federal levels. Education is probably the most important enterprise a society can do. What are your thoughts on how you are going to guide Mines?

ADMIRAL TRULY: I'm glad you're asking me such puffball, easy questions!

Somehow we have arrived at a situation where, in my view, there is a strong disconnect between what a great public university is and ought to be. You have a situation where universities are supposed to be thought leaders. They're supposed to be places that students and faculty and university presidents alike can look at the world and pick the toughest, long-term problems and talk about them, debate about them, work on technologies that will solve them, work on social cultures that will understand them. And yet we're talking about tuition rates and the level of state funding rather than these larger problems. I'm not blaming anyone. But here we are — and it's not that tuition is not an important subject — but it's not the only subject.

DR. POATE: Our undergraduates are focused. They want to be engineers and scientists. For an incoming freshman, what advice would you give?

ADMIRAL TRULY: I'd say: This is your chance. Prepare yourself for the next few years to work like hell. Play hard. Get to know yourself. At the other end, you'll be well-positioned for a career.

DR. POATE: If and when they graduate, and you're at the graduation ceremony, what are you going to tell them to do?

ADMIRAL TRULY: I can remember listening to the commencement speech on my graduation day over 50 years ago, and I remember saying to myself, 'If I can do what I just did, I can do anything.'

DR. POATE: Well, you did! We were chatting in my office before and I learned that you are a Robert Frost scholar. "The Road Not Taken." Tell us more about that.

ADMIRAL TRULY: Well, I do love Robert Frost and I love that poem, although it's not my favorite one. There have been a couple places where I thought about — and turned down — one opportunity for another. One of the early ones: I was in the Navy. I had done my first tour in a Navy fighter squadron at sea and I had always intended to get out of the Navy and go to graduate school. And in the Navy, when you're coming off that first sea tour, there are three things that you could do. You could go to graduate school. The Navy would send you. You could go fly for the Blue Angels. Or you could go to test pilot school. The road I didn't take was to go to graduate school. I took that other road to test pilot school — and it worked out okay.

Another one when I was little bit older: The head of the Smithsonian tried to talk me into becoming director of the Air and Space Museum in Washington. The most visited museum in the world. I decided not to do that. And within six months, I was in Colorado. So it turned out all right.

DR. POATE: It certainly turned out well for us. Thank you, Admiral Truly.

EARTH

UNLOCKING UNCONVENT



By injecting fluid under high pressure into a well, petroleum engineers break the rock all around it. They also mix sand or tiny beads of kiln-fired clay called “proppant” with their fracturing fluid. The mixture varies greatly in color and texture; beakers of it can resemble charcoal-grey instant dried yeast or tan, dry tapioca pearls. When these micro-ball-bearings infiltrate the fissures as the rock breaks, they help prop the cracks open.



UNCONVENTIONAL OIL AND GAS

In the basement of Alderson Hall, in a lab painted butter yellow and crimson with soaring, utilitarian square concrete pillars, amongst a hodgepodge of machine room detritus and laboratory equipment, is a non-descript apparatus that does something extraordinary. It makes a rock behave as if it isn't there.

Specifically, the rock responds as if, instead of being in a room in the basement of the petroleum engineering building at Mines, it's in its ancestral home — perhaps thousands of feet from the surface, hot and under tremendous pressure. In the conditions under which it has spent millennia, the rock is stressed and sometimes pushed to the breaking point. How? Mines Petroleum Engineering Professor Azra Tutuncu, or one of her students, uses the machine to squeeze, heat and perhaps shake the rock. The machine sits on rocking, gel-insulated feet to make sure it doesn't shake the building or break the floor.

Tutuncu wants to understand the rock's properties, and find out under what conditions, and how, the rock will crack. This is important because, far away on the desolate sagebrush steppes of Wyoming, or under the undulating grasslands of the Great Plains, the vast rock formation from which this sample came is saturated with gas. Gas that can only be extracted by breaking that rock.

To figure out the best, most efficient and most environmentally sound way to do so, Mines is the go-to university in the U.S. Its Unconventional Natural Gas and Oil Institute (UNGI), which Tutuncu directs, helps Mines fill a role only an academic institution can provide. It fosters unconventional research collaborations, provides students training available virtually nowhere else in America, and partners as an honest broker with industry and government to help train effective government regulators.

"UNGI's role is to be a leader in research, where we can collaborate with the worldwide oil industry, state and government agencies, and other academic organizations," Tutuncu said, "and to unlock these resources appropriately in an environmentally friendly and economically viable fashion."

WHEN DRILLING GOT HARDER

For many years, all that was necessary to harvest oil and gas was to pluck the low-hanging fruit of formations from which the oil sometimes literally gushed from the ground. And, if you believe the movies, under the fountainous deluge, the drillers always danced for joy. But in the last few decades those conventional reservoirs, from which oil and gas easily flowed, began to run out.

Meanwhile, an enterprising driller named George Mitchell began looking in the 1980s at a formation called the Barnett Shale — with an eye toward how to crack it. Shales are dense sedimentary rocks produced from compressed silt or mud. They may hold hydrocarbons abundantly in the pores of the rock, but the pore spaces are not very permeable. These shales often form the upper and lower seals on conventional petroleum reservoirs.

Drillers had noted for years that when they bored through the shale, they would encounter occasional pockets of gas. But the rock as a whole was far too impermeable to yield the gas trapped inside it. Mitchell knew the formation could produce a huge quantity of gas if only he could figure out how to make the rock release it in an economically feasible way. But how? Mitchell and his engineers solved their problem by using an existing technique, in new and improved ways, on the recalcitrant shale. The technique was hydraulic fracturing. Later the process of horizontal drilling — a critical advancement — came into use.

To drill horizontally, engineers drill down into the gas-bearing rock and then gradually turn the bit horizontally into the rock layer that contains the hydrocarbons they're after. A well horizontally drilled into the reservoir formation vastly increases the surface area of a well exposed to the oil-or-gas-bearing rock. In the case of a 100-foot-thick layer and a one-foot-diameter well, they theoretically can go from 160

square feet to 3,200 square feet of exposed petroleum-yielding rock. By drilling multiple horizontal wells in multiple directions from one well pad, they multiply the effect.

Why hydraulic fracturing? One great way to make tight shale give up petroleum is to make your own escape route for the gas by infiltrating it with fissures. "With most of those formations," said Jennifer Miskimins, associate professor of petroleum engineering at Mines, "unless you crack them a little bit, they're not going to flow at all."

By injecting fluid under high pressure into a well, petroleum engineers break the rock all around it. They also mix sand or tiny beads of kiln-fired clay called "proppant" with their fracturing fluid. The mixture varies greatly in color and texture; beakers of it can resemble charcoal-grey instant dried yeast or tan, dry tapioca pearls. When these micro-ball-bearings infiltrate the fissures as the rock breaks, they help prop the cracks open.

Because the well bore is horizontal at depth, the well can be fractured sequentially dozens of times — the number is increasing as petroleum engineers become more experienced. With the horizontal bore, the multiple wells possible from one pad, and the fracturing process, it's now possible for one well pad to replace what would have formerly required 1,000. A well pad that, in the past, would have allowed access to 160 acres of the productive rock can now access 150,000 acres.

This vast improvement in the surface area of petroleum-bearing rock from which drillers can extract gas — along with increasing gas prices — enabled unconventional gas to become economically viable. And as more and more drilling companies, large and small, have rushed to share in the bonanza, unconventional gas production has soared. A map of shale basins under development today looks vastly different and more colorful than maps of just a few years ago.



Courtesy of Zach Aman

OTHER FORMS OF UNCONVENTIONAL PETROLEUM

Gas from tight shale is not the only unconventional petroleum going into production. A smorgasbord exists of unconventional options ranging in difficulty-to-extract from fairly easy to devilish. There are gas sands, which have ultralow permeability that make them a particular challenge. Wyoming's Pine River Basin is of this type, as well as the fields near Rifle, Colo. There is coal-bed methane, in which methane is released from coal by pumping out the water saturating the rock. There are heavy oil sands (found extensively in Canada), oil shale (also found near Rifle and not to be confused with shale gas) and gas hydrates — methane molecules encased in ice — found in the far north. As the price of petroleum increases, all these resources may have their time.



JENNIFER MISKIMINS

“You will be amazed at some of the very giant shale basins we have been dealing with in the last two to three years that were not even on the map in 2005,” said Tutuncu. Presently about 30 percent of U.S. natural gas production comes from unconventional sources, but by 2035, said Tutuncu, it will be beyond 50 percent.

What makes unconventional shale gas even more attractive is this country’s potential reserves, which worldwide rank second only to China. For those interested in energy independence for the United States, this makes shale gas an attractive option. “In the U.S. we’re on the screaming decline for [conventional] natural gas,” Miskimins said. Just a few years ago, permits were being issued to California ports for importing liquefied natural gas from abroad. Now, she said, shale reservoirs make up about 50 percent of what’s produced on a daily basis in the U.S.

LEADING THE PACK

From the beginning, Mines has led and continues to lead the way in researching and improving unconventional oil and gas extraction methods. “Mines was looking at unconventional reservoirs before anyone called them unconventional,” Miskimins said. Mines has studied the geology of the Piceance and Green River Basins of Wyoming and the Niobrara play around Chugwater, Wyo., for decades, she added.

Hydraulic fracturing of gas shale is a unique niche for Mines, according to Miskimins. The university’s research focuses on:

- understanding the mechanical behavior of rocks and how they respond to various sensing — often seismic or acoustic — methods

that petroleum companies use to gauge them

- creating models that accurately simulate how reservoirs will fracture and behave over time
- understanding the geology of the shale beds

To capitalize on this expertise, two years ago Mines Vice President of Research John Poate asked Miskimins and John Curtis, Mines professor of geology and head of the Potential Gas Committee, to form an institute specifically focused on unconventional reservoirs. This was the seed of UNGI, aimed at bringing bright minds from different departments on campus together to look at big ideas and projects in unconventional oil and gas.

Today UNGI promotes communication and new research consortia among faculty in many different departments. UNGI presently includes 41 Mines faculty and more than 30 graduate students. One of the first consortia to emerge from this group, the UNGI Coupled Integrated Multiscale Measurement and Modeling effort, involves faculty from nine different departments, five Department of Energy national laboratories, and several independent and major oil companies.

In addition, UNGI plans to be an impartial resource for the public, industry and government in addressing the environmental concerns associated with hydraulic fracturing, researching claims of damage or contamination and seeking ways to improve the process, reducing or eliminating contamination, and saving water. Presently, ground and surface water contamination by fracturing fluid is the largest

perceived risk, but habitat destruction by well pads and the sheer quantity of water required for hydraulic fracturing are additional concerns. In 2010, for instance, 10,500,000 gallons of water were required to fracture one well 5,000 feet long in 20 to 25 fracturing stages.

“The public has every right to be concerned about this,” Tutuncu said. “That is why we are looking into the scientific and engineering facts behind hydraulic fracturing and how can we reduce environmental impacts and save water.”

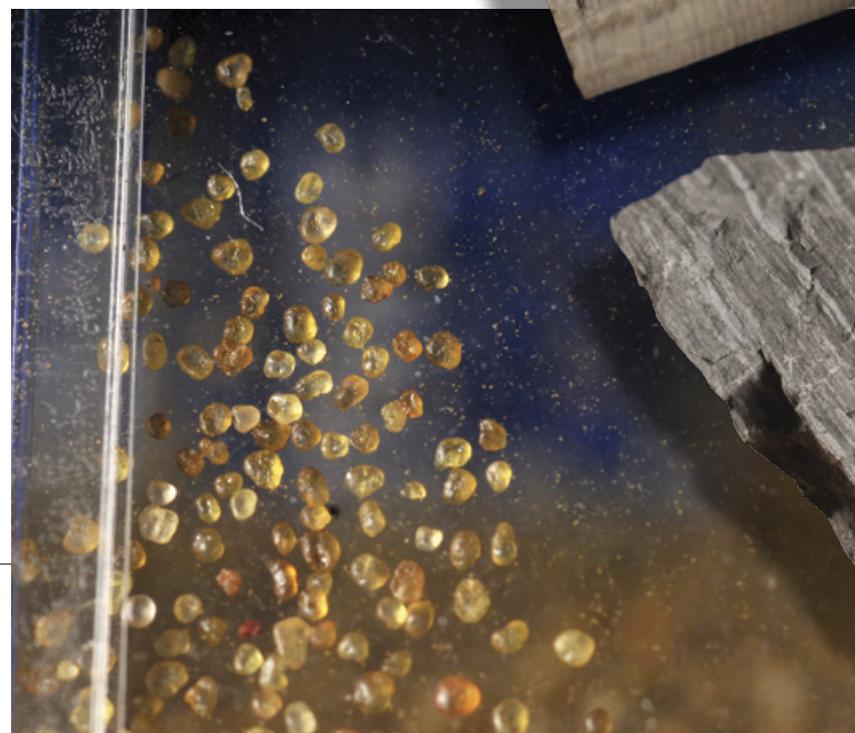
Tutuncu’s own rock-shaking-and-breaking project in the basement lab has environmental aims at heart. Better understanding the properties of the rock a company will fracture helps the company minimize the water and chemicals they will need to get the job done. Her setup will also allow her team to directly introduce different fracturing fluids into the sample and measure the response. One method they will test is to use a simple solution of salt and water with no other chemicals, Tutuncu said. Because shale usually demands extremely high water pressure to break, increasing the salt concentration makes the rock more breakable, so the process requires less water — and only a trace amount of chemicals may be needed to do it.

The core cells at the heart of the setup were specially designed and ordered by Tutuncu to radically improve on existing methods for testing. There is no experimental setup anywhere else in the world with the same capabilities to implement the real reservoir conditions. A single, accurately shaped cylindrical core sample can be tested inside, rather than an unrealistically sized and shaped series of blocks typical of current testing methods. Because shale is thinly layered, the stresses are very different in different directions of the rock, and therefore the size and shape of the samples matter.

SHARING THE KNOWLEDGE

UNGI also plans to reach out and help other countries begin investigating their reservoirs. The sudden interest in unconventional petroleum fields has caused some countries to realize they are sitting on top of an unexpected windfall. “Argentina, which was not even in the oil play at all in the past,” Tutuncu said, “is unexpectedly number three in terms of total recoverable unconventional shale gas reserves.”

Argentina will need help to exploit those reserves. Scientists at Mines are curious to compare the characteristics of Argentina’s shale with our country’s to understand if the techniques we use on our basins are transferrable to theirs. UNGI hosts visiting scholars from many countries and likewise fosters research into the similarities between various U.S. basins and world shale plays to speed production in those countries.



The Mines Petroleum Engineering Department offers three-week, condensed “Super School” training classes every summer on the fundamentals of petroleum engineering for oil and gas company employees with non-petroleum-engineering backgrounds.

In addition, the department and UNGI — in partnership with ExxonMobil and GE Oil & Gas, the University of Texas at Austin, and Penn State University — have initiated a public service effort to train government regulators and policymakers in the areas of shale reservoir drilling, completion, hydraulic fracturing and production.

Michael Parker, a technical advisor in the Safety, Health and Environment group of Exxon-Mobil Production Company, said that public confidence in oil and gas extraction is built through strong, sound regulation enforcement, and one of the publicly perceived weaknesses in the industry has been a lack of good regulation.

Exxon-Mobil and GE Oil & Gas saw that they had the ability to improve competence among new regulators by providing a short course that would teach those with biology or environmental science backgrounds the fundamentals of the business they will regulate. But they knew they weren’t the ones to do it. That’s when they turned to Mines. “We know what we want, we’re just not quite sure how to get there,” Parker said, “and that’s the void they’re filling for us very effectively.”



Outcrop and core samples of dark, organic-rich shale.

MINES PETROLEUM ENGINEERING GRADUATE PROFILE: PATRICIA CUBA

Patricia Cuba — a mechanical engineer by training — worked as a field engineer pumping hydraulic fractures for two years before she decided to go back to Mines and earn a master’s degree in Petroleum Engineering. She wanted to better understand exactly what she was doing out there. “As a field engineer you are able to go and pump a job,” she said, “But you don’t really know about the reservoir.”

She approached Miskimins about a thesis project, and Miskimins suggested studying a complex type of sandstone that had long given petroleum engineers headaches: complex fluvial sandstones.

Planning how to fracture a rock formation is one of the most crucial things a petroleum company can do to maximize recovery and efficiency. But what happens when the rock outcrop you want to fracture is made up of complex, meandering, river-deposited sediment? This type of rock varies greatly horizontally and doesn’t fit well with a traditional fracturing layer cake model, which assumes horizontal continuity in rock layers. Inaccurate models can lead to overestimates of fracture length, geometry and resultant gas production.

Cuba’s project was to improve these models, using real-world data from the Greater Natural Buttes formation in Utah, to make them more accurately reflect the geometry and geology of complex sandstone outcrops. She also wanted to see what might be the best rule-of-thumb practices for a petroleum engineer in such a field.

One conclusion was that if a driller increases hydraulic fluid volume by 30 percent in such a field, this can improve production because fractures will grow farther and drain more of the small sandstone reservoirs inherent to complex alluvial deposits. In North America and Europe, a consortium of companies, including Conoco-Phillips, Shell, Total, ENI and Wintershall, are using the models she helped create for her thesis on fields they are developing. “From this research

I learned you better understand what is going on with your reservoir,” she said, “so you can know what is the best way to apply or to stimulate your well with a hydraulic fracture.”

Cuba is now a completions engineer for Anadarko working in the same field she studied for her thesis: the Greater Natural Buttes in Utah’s Uinta Basin.

ENERGY



KEY TO SUPER COLLABO



CRISTIAN CIOBANU

CAROLYN KOH

AMADEU SUM

REED MAXWELL

RATIONS?

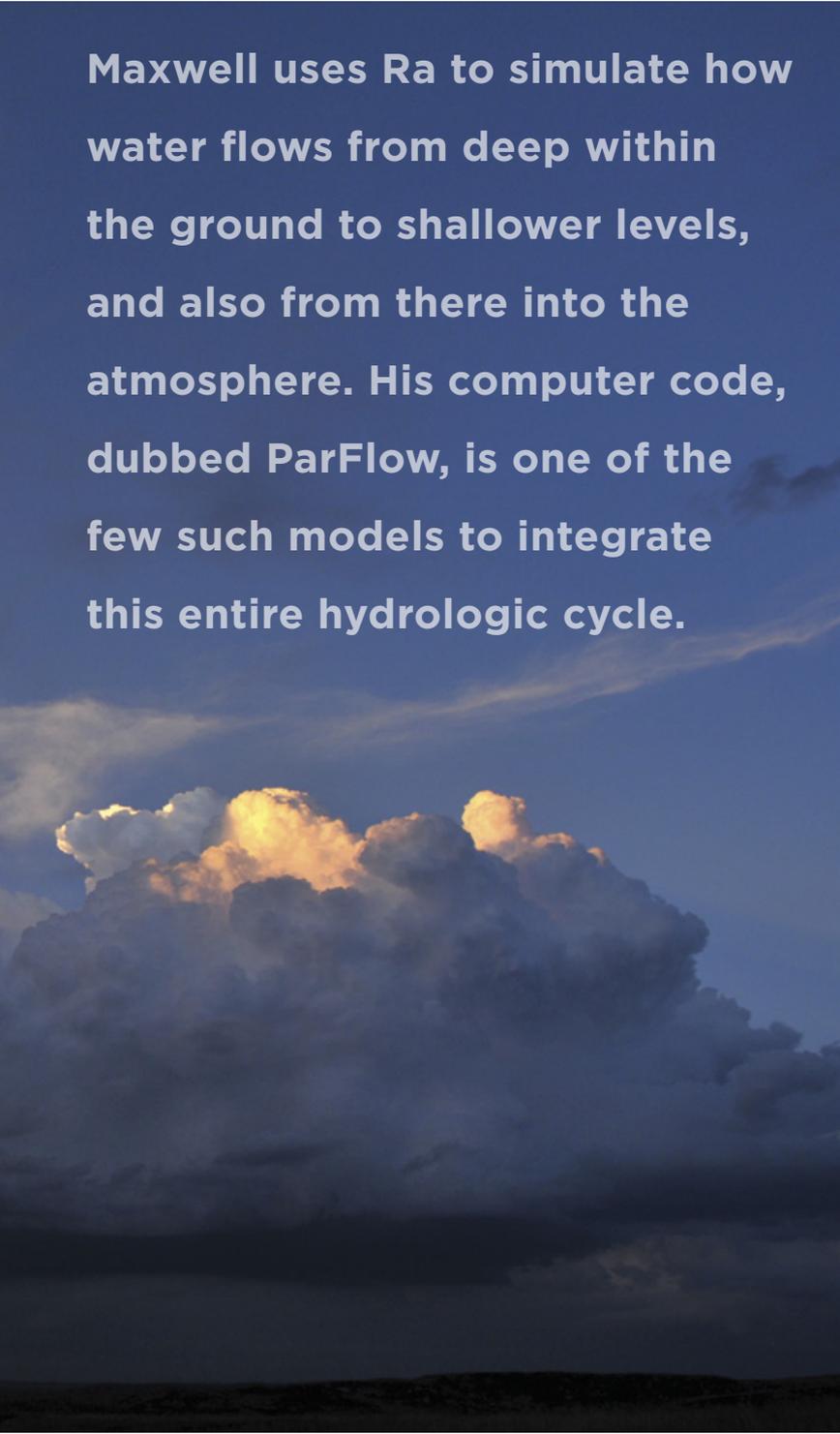
SUPERCOMPUTING

This is a story of humans and hardware. What happened when professors, tops in their different fields of energy research, gained campus access to a world-class supercomputer?

The story began four years ago with the institutional vision to bring a supercomputer named Ra to Mines. Dag Nummedal, director of the Colorado Energy Research Institute, and Physics Professor Mark Lusk had been working to acquire a supercomputer, and when Vice President of Research and Technology Transfer John Poate got involved, “the idea resonated campus-wide,” said Lusk.

With the horsepower of Mines leadership behind this well-timed initiative, it became a commitment to much more than hardware. Five years, one supercomputer, 10 new faculty hires, 15 classes, 60 PhD students and 120 journal publications since that original vision, Mines has become a global leader in computationally guided energy science research.

The initiative has made a huge impact on research volume, led to many important discoveries, and catalyzed interdisciplinary collaboration across campus. More than 90 percent of Mines’ academic departments are pursuing projects supported by the Golden Energy Computing Organization. As scientists from different areas come together, ideas begin to cross-fertilize and surprising synergies emerge. As Lusk notes, “Once all these people start working together under one virtual roof, good things happen.”



Maxwell uses Ra to simulate how water flows from deep within the ground to shallower levels, and also from there into the atmosphere. His computer code, dubbed ParFlow, is one of the few such models to integrate this entire hydrologic cycle.

SYNERGY IN ACTION

One of the new supercomputer hires was Amadeu Sum, a professor in the Chemical and Biological Engineering Department and co-director of Mines' Center for Hydrate Research. He used Ra to explain the nucleation and growth of hydrates, and his work landed on the cover of *Science*.

On another side of campus, REMRSEC, the Renewable Energy Materials Research Science & Engineering Center, was chosen for funding by the National Science Foundation in part due to the computing power Ra could bring to the table.

Lusk's solar cell work with REMRSEC on multiple-exciton generation (MEG) was successful. MEG theorizes it is possible for an electron that has absorbed light energy to transfer some of that energy to other electrons, resulting in more electricity from the same amount of absorbed light.

In a cross-fertilizing leap, REMRSEC decided to look at hydrates as a way to store hydrogen. The center provided seed money to Carolyn Koh, a professor in the Chemical and Biological Engineering Department, to lead a combined team of REMRSEC solar energy scientists and Center for Hydrate Research experts. Together they developed a computer analysis to assess the potential of hydrates for hydrogen storage.

Then they began thinking of other materials that could be assembled into the cage-like clathrates. Could they build a silicon clathrate structure to store hydrogen? Using experimental facilities at the National Renewable Energy Laboratory (NREL), they determined the answer was yes.

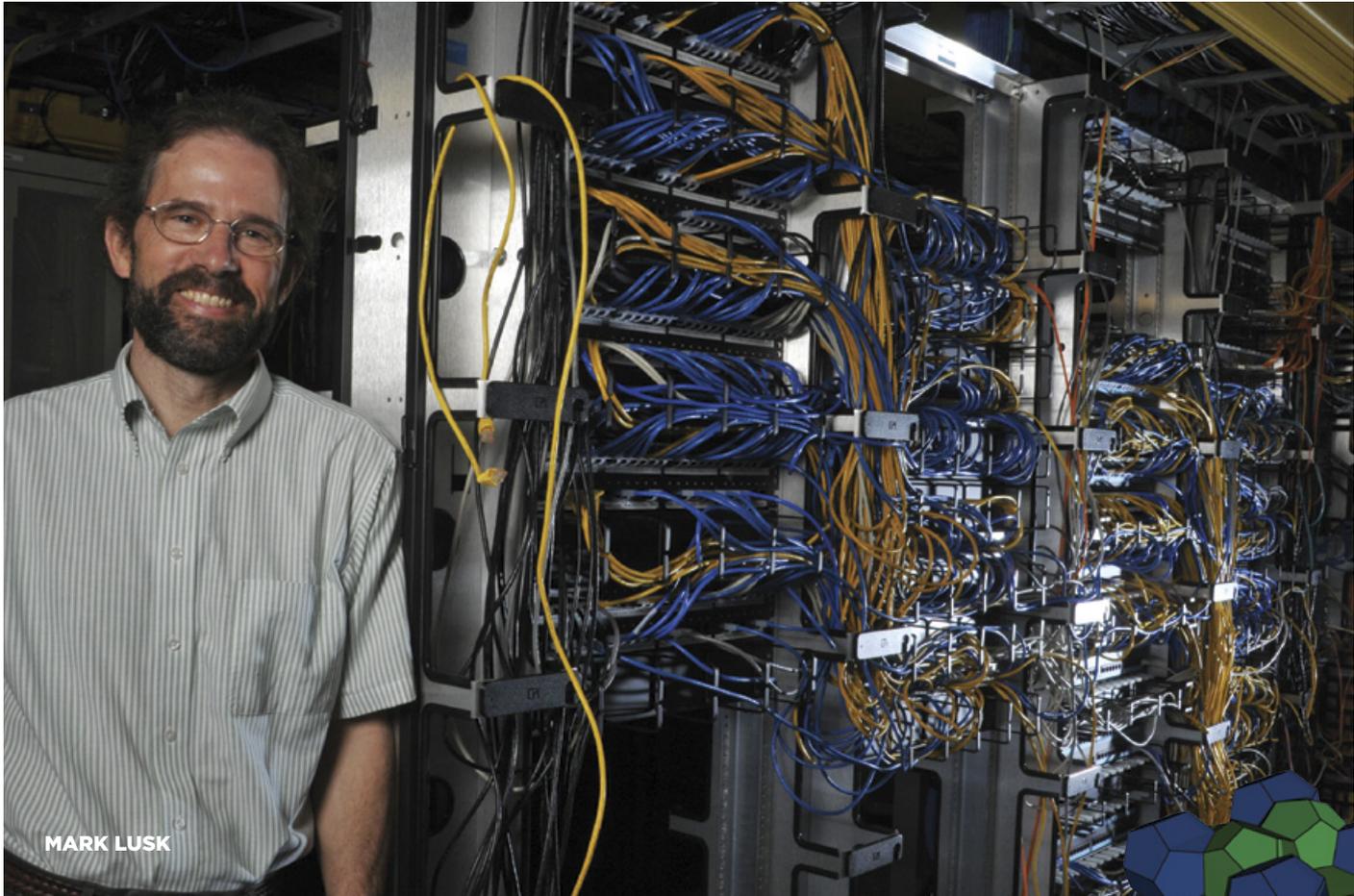
The synergy continued. What are the photovoltaic properties of these new silicon clathrates? Can they be used to build a better solar cell? The answer, once again, appears to be yes.

In summary, hydrate engineers and solar energy physicists have founded two new facets of energy research because a world-class supercomputing facility came to Mines. "The successes that have come from our original vision have been snapping together a Lego™ at a time," said Lusk. "We have a cool system going now and there's no end in sight."

A NEW SEASON

Now plans are under way to purchase a new machine to become the campus flagship for high-performance computing, with Ra maintained as a set of smaller clones for less demanding projects and student training. Requests for bids have gone out to industry, and by autumn 2012 the new machine should be on campus, humming alongside its predecessor.

The next supercomputer will be a radical step forward, with at least five times Ra's computing power and roughly 16,000 processor cores to Ra's 2,144. Even so, it will consume just a fraction of Ra's physical space and electrical power, thanks to technological developments over the past few years.



Ra's successor will give a boost to many of Mines' most ambitious efforts, and Lusk predicts the new machine will be the basis for frontier energy research for years to come. "It's exciting to be part of this vision," he said. "The campus now fields several big teams that do high performance computing in close collaboration with experimentalists. The original leadership has evolved into some amazing self-assemblies, and I can't wait to see what advances come out next."

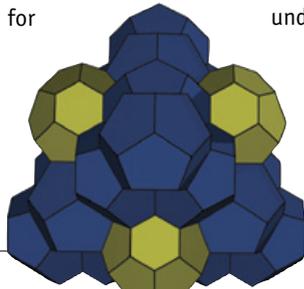
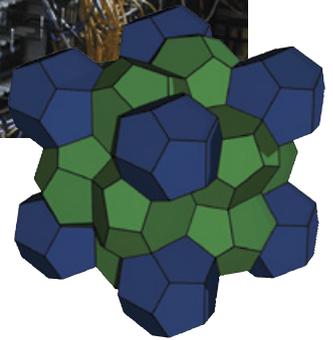
CLATHRATE HYDRATES

Researchers have achieved the first real insight into the birth and growth of the cage-like structures known as clathrate hydrates. These materials can form naturally — for example, out of natural gas in gas pipelines, where they form an "icy slush" that can accumulate in the pipelines and eventually clog the flow. Using Ra, Mines researchers have been able to simulate for the first time the molecular processes that

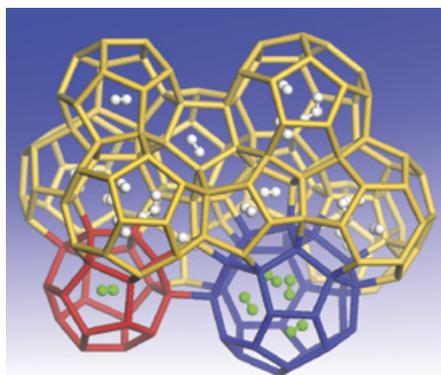
cause such hydrates to nucleate and grow, adding — atom by atom — to each rigid molecular cage.

It's not an easy task. Hydrates form out of disordered systems, with atoms starting out adrift and then coming together in precise ways to form a complex network of water molecules enclosing gas molecules. Simulating how that transition happens takes a lot of computing power, said Sum. "That's why we need to use large resources like we have on campus to do these large and long simulations," he said.

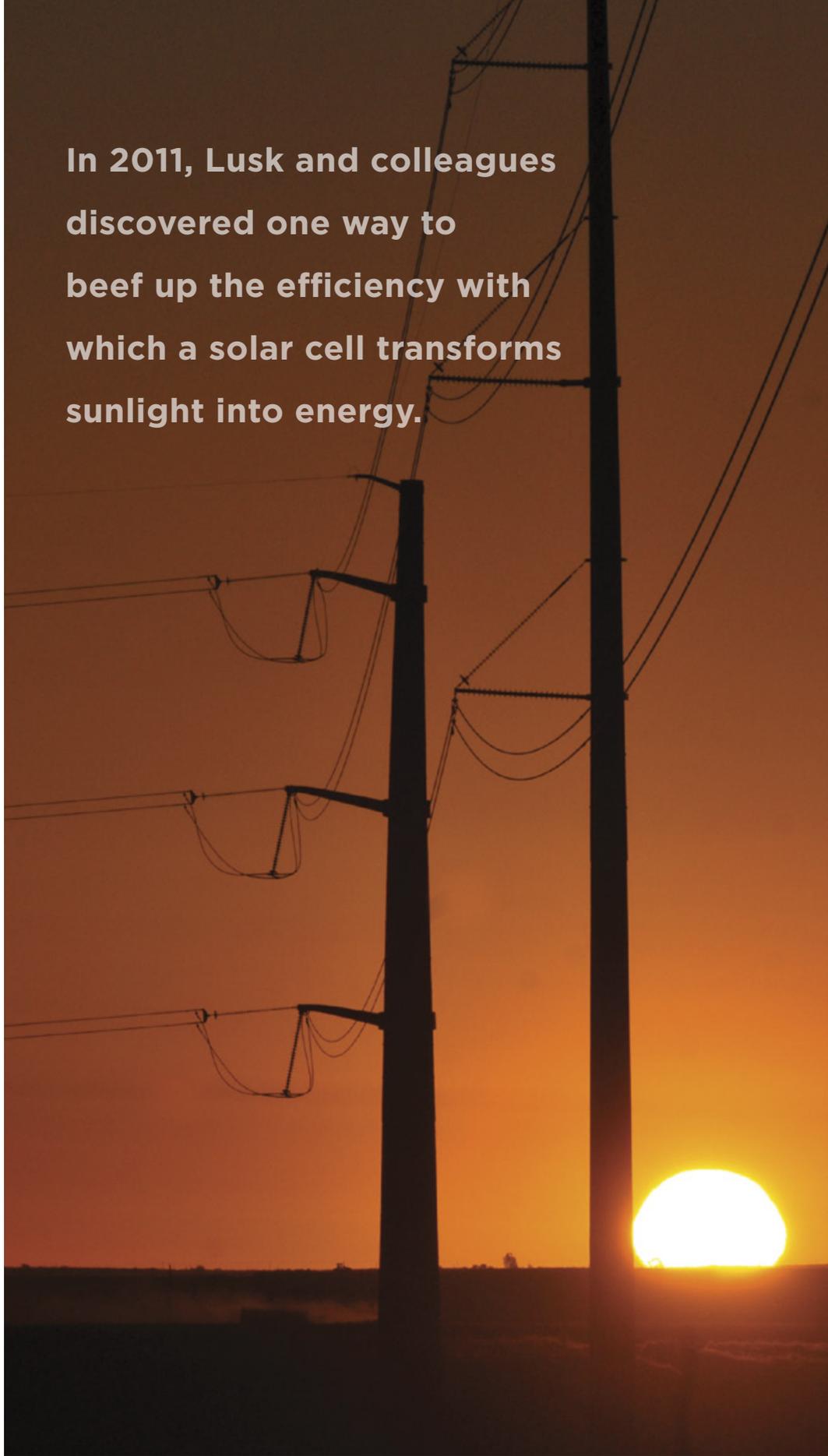
Knowing how hydrates nucleate will help researchers better understand how to prevent/control them from forming and harness them for useful purposes as well. Hydrates will make an impact through the recovery of methane gas from natural hydrate deposits in the permafrost and ocean seafloor, and the utilization of hydrates as an energy storage medium for natural gas and hydrogen.



In 2011, Lusk and colleagues discovered one way to beef up the efficiency with which a solar cell transforms sunlight into energy.



Hydrogen molecules (white atoms) can be pumped into all-silicon clathrate cages (light brown atoms) and they remain stable there at room temperature and pressure. The clathrate structure is composed of interlocking cages of two different sizes which are highlighted at the bottom in red (20 silicon atoms per cage) and blue (28 silicon atoms per cage). The capability of silicon to perform in this way was computationally predicted by our team and was experimentally realized using facilities at NREL.



OIL AND GAS

With the need for traditional fossil fuels still great, Associate Professor Paul Sava is using Ra to discover new sources of oil and gas. Active in the Center for Wave Phenomena in the Geophysics Department, Sava specializes in developing new methods for probing the earth's interior with seismic waves. Doing so requires running simulation after simulation of how quickly waves travel through the earth, then comparing those to real-world observations to see how closely the two match.

So far, Sava's team has been able to refine a flagship exploration technique used in industry. Rocks inside the earth respond differently to excitation by seismic waves, for example by enabling their propagation at different speeds. The Mines scientists exploit such differences between rock strength to compression or shearing due to seismic activity, which enable them to infer the geologic structure deep inside the earth. Updating this knowledge allows oil and gas companies to better predict where a promising prospect might turn into a lucrative discovery. "The information relevant to them requires a big computer like this," Sava said.

HYDROLOGY

Mines' dedication to high-performance computing has helped draw high-profile faculty to the university. "When I showed up, Ra was being unboxed," said Reed Maxwell, a hydrologist who moved from the Lawrence Livermore National Laboratory in California.

In the Department of Geology and Geological Engineering, Maxwell uses Ra to simulate how water flows from deep within the ground to shallower levels, and also from there into the atmosphere. His computer code, dubbed ParFlow, is one of the few such models to integrate this entire hydrologic cycle. Maxwell has used ParFlow to explore all sorts of important questions, such as how agriculture draws down groundwater and how changes in hydrology affect local atmospheric patterns — for example, the wind energy potential over a particular plot of land.

Because his simulations require so much computing power, Maxwell uses not just Ra, but also several other supercomputers, including ones at the Oak Ridge National Laboratory in Tennessee and at a facility in Jülich, Germany. "I always envision running on a range of supercomputers," he said.

Most recently, Maxwell has built a high-resolution hydrological model of the entire continental United States, which covers 6.3 million square kilometers at a resolution of 1 kilometer. This simulation, which he said is one of hydrology's "grand challenges," is tied into leading climate models so that Maxwell can, for example, probe how water flow may affect regional climate change in the decades to come.

MATERIALS

From the scale of continents down to the scale of nanoparticles, Ra's simulations are doing it all. For Cristian Ciobanu, a materials scientist in the Department of Mechanical Engineering, Mines' computing resources involve the very small. He works to understand the

basic chemistry and physics of materials crucial for energy applications, from lithium-ion batteries to biomass to solar cells. "In all these cases, the campus facility is important," Ciobanu says. "It's basically a lot of computing power on site, and you can do things faster, closer to real time."

For instance, he and his collaborators at NREL have shown that using a material as common as quartz can lead to an increase in the capacity of lithium-ion batteries over the first couple hundred cycles of charging and discharging, thus hinting at new ways to prolong battery life. Other simulations have shown that adding nanoparticles of gold or other precious metals to a particular chemical process speeds up the reaction, while also making it yield a desired reaction product, hastening the conversion of biomass into energy. Ciobanu is now running calculation after calculation on Ra to find the best possible shape and composition for nanoparticles to catalyze the biomass conversion reactions. With such information, an experimentalist can make nanoparticles that work efficiently the first time around, without having to run through the trial-and-error of testing particle after particle in real life.

For solar cells, Ciobanu has been testing how to make the perfect nanoparticles out of germanium and tin with the best electronic properties for absorbing light. Such alternative materials might be used in future photovoltaic cells, especially if they can be designed through supercomputer simulations and then tailor-made to fit those designations.

PHOTOVOLTAICS

Lusk is also using the power of Ra to figure out how to make better photovoltaics. In 2011, he and colleagues discovered one way to beef up the efficiency with which a solar cell transforms sunlight into energy. Supercomputer simulations done at Mines suggest that in a specially designed material, a particle of light (photon) can knock loose not just one electron (its flow creates the electricity that powers solar cells) but two or more, in a process known as multiple exciton generation. The set of excited electrons would turn more of the original solar energy into useful electricity because not as much is lost to generate heat.

The race is now on to make better photovoltaic materials by exploiting multiple exciton generation and other quirky quantum mechanical properties that Lusk's team has discovered. They use Ra to model how to best design what amounts to a new form of matter composed of quantum dots. These tiny particles, just a nanometer or two across, both help to capture solar energy and to move it through the solar cell to create useful current.

Lusk is also looking to build on nature's own solar cell — the leaf — by co-opting its photosynthetic tricks. Nature has evolved some very clever ways of harvesting solar energy, but its solar panels don't last very long. "We're using the computer to unravel some of the quantum mechanical secrets that are going on all around us. And then we want to use that information to build inorganic solar cells that do the same thing better and without wearing out as easily," Lusk said.

ENVIRONMENT

WATER: MASTERING THE MONU





MENTAL CHALLENGE

Take raw sewage flowing from a major apartment complex. Send it through a 2 millimeter screen. Let a flora of microorganisms feast on it for a while. Filter it — this time through pores just 50 billionths of a meter across. Don't touch it with a single water-treatment chemical.

That's what the above-ground sequence batch membrane bioreactor does, and the six gallons per minute flowing out are cleaner than the effluent from most wastewater treatment plants. And unlike the massive, in-ground infrastructure just downriver of many of our metropolitan areas, the bioreactor is portable. The fruits of Colorado School of Mines' Advanced Water Technology Center's (AQWATEC) signature project could form the nodes of a next-generation network of water-treatment facilities, able to reuse water locally for things like irrigation and toilet flushing, saving pumping energy and infrastructure costs, while reducing water demand.

In the control room, Tzahi Cath, a Mines professor and director of AQWATEC overseeing this facility, lifted the lid of a vat and dipped in a Pyrex™ measuring cup. It looked like ... water. "That was sludge a few minutes ago," he said. "There are technologies that can make good water from almost any source."

The AQWATEC facility, just downhill from the apartments at Mines Park, is one of many water research efforts led by Mines faculty and students. Their studies of water begin with aquifers 1,000 feet down and continue through the turbulent interface of soil and the air above. Along the way, they use tools as diverse as a managed aquifer recharge site in Colorado's eastern plains, a wooden wind tunnel built in a converted swimming pool, and the Jaguar supercomputer at Oak Ridge National Laboratory. They aim, collectively, to ensure safe, clean water for people and the environment.

It's critically important work. A recent United Nations report described global water challenges ranging from water supply to sanitation infrastructure. More than 80 percent of the world's wastewater goes untreated, according to the report. Furthermore, these challenges occur amid what the U.N. called "unprecedented" increases in food demand, rapid urbanization and climate change, and they aren't limited to developing countries.

"Fresh water supplies are unlikely to keep up with global demand by 2040, increasing political instability, hobbling economic growth and endangering world food markets, according to a U.S. intelligence assessment," Reuters reported in March 2012.

In the U.S., the gap between budgets and needed upgrades to half-century-old water infrastructure is wide and growing, said Professor Jörg Drewes, a co-director of AQWATEC. "We need to come up with new ideas, to be innovative and work with the funding we have available," Drewes said. "It's not enough to merely replace what we have today."



“It’s all about finding new ways to use and reuse water.”

JOHN MCCRAY

NSF FUNDS NEW WATER RESEARCH CENTER

New solutions will require expertise across a broad swath of science and engineering, as well as legal, political and business realms. In 2011, Mines joined forces with Stanford University, the University of California at Berkeley and New Mexico State University to create the first NSF-funded Engineering Research Center devoted to water issues. It’s called Re-inventing the Nation’s Urban Water Infrastructure, or ReNUWIt.

Mines’ central role in ReNUWIt came in the wake of years of investment in labs and research infrastructure and the development of one of the country’s leading water-research programs, said Drewes, who is also ReNUWIt’s director of research. He is among a dozen Mines faculty involved in a 10-year effort to transform traditional models of

water use to reduce consumption, recover and reuse water, cut energy use in water systems, and harness wastewater nutrients to improve urban habitats. Between the NSF and corporate partners, the program is expected to reap \$80 million in research funding and enable an unprecedented degree of cross-institutional, multidisciplinary collaboration.

“The biggest benefits are really the collaboration and the long-term nature of the funding,” Drewes said. “We’re looking at how this might play out in 20 or 30 years, rather than how to help a certain utility with a particular research problem.”

The ReNUWIt projects at Mines are diverse. PhD student Ryan Holloway is working on tuning the AQWATEC bioreactor so its output varies by season. The idea is that, during the summer irrigation

season, the system can be tuned so more organics and nutrients can exit for use in outdoor watering, cutting freshwater and synthetic fertilizer use. This summer, they'll be testing it on a half-acre plot outside the facility.

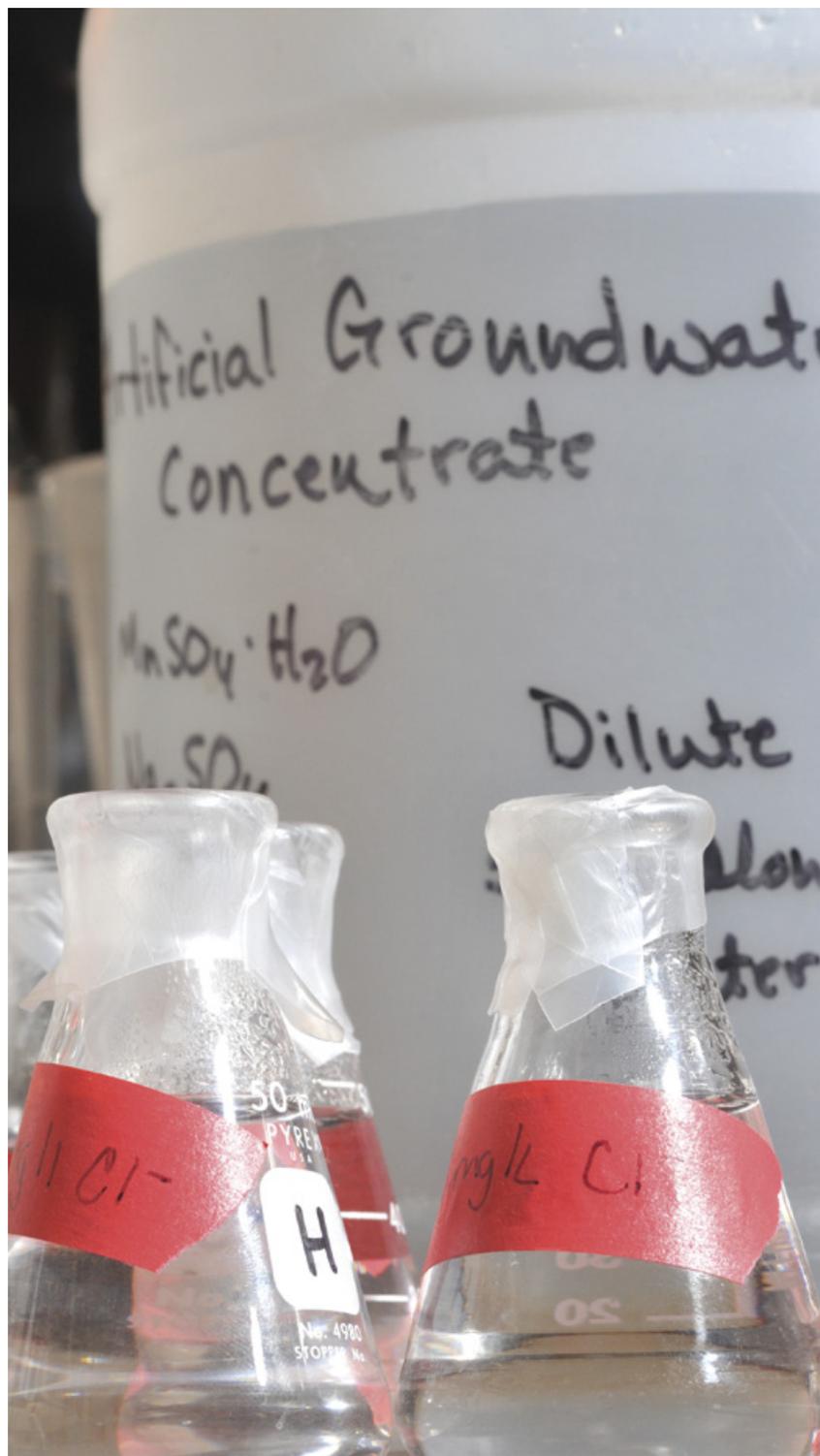
A few feet away, PhD student Dotti Ramey paints part of a microscope slide with red nail polish. Algae avoid nesting on that part, she explained. Bubbles rise through nine glass jugs backlit by squint-inducing grow lights. Hints of algae cling to bottlenecks. Outside, stainless-steel paddle wheels turn in what look like giant bathtubs. Rather than warm suds and yellow rubber duckies, the contents are cold and green. The work is part of a collaboration with startup and ReNUWIt partner BioVantage Resources, with the aim of understanding how wastewater could be used to nurture algae, which in turn treats the wastewater. The algae could be turned into useful lipids, biopolymers or even fuel.

Managed aquifer recharge is another Mines/ReNUWIt focus. This work is led by Professor Tissa Illangasekare and the Center for the Experimental Study of Subsurface Environmental Processes (CESEP). The idea is to apply concepts of rural managed aquifer recharge. This involves building ponds with very particular microbiological and subsurface features so clean water seeps back into aquifers rather than evaporating or flowing downstream to urban wastewater treatment systems. Pulling it off at a much smaller scale (think large swimming pools rather than football-field-sized ponds) demands expertise in chemistry, hydrology, biology and engineering, Drewes said.

ReNUWIt's work extends past the physical into the managerial. Water managers keep tabs on a small number of big facilities. With an integrated network of AQWATEC-style plants enabling local reuse across a metropolitan area, managers will need tools to monitor it all and make smart adjustments. Mines Professor Reed Maxwell is working with UC Berkeley resource economist David Sunding to develop hydrologic and economic models to help quantify the costs and benefits and, ultimately, manage much more complex water infrastructures.

"It's all about finding new ways to use and reuse water. That's more than just science and engineering because you have to convince the politicians and the water managers, who are very conservative, to take a chance and do something in a different way," said John McCray, a ReNUWIt investigator and director of Mines' Department of Civil and Environmental Engineering.

Collaboration is woven into ReNUWIt's fabric. Mines' expertise in geology, hydrology, biology, engineering and numerical modeling is now connected with Stanford Law School's legal and policy expertise and UC Berkeley's economic savvy, Drewes said. The extended team has the breadth to handle the full spectrum of issues that crop up in attempts to reinvent something as fundamental as water infrastructure. Such cooperation might involve, for example, figuring out the best microbial mix to purify water captured after a storm, designing a system to enable it, and ensuring that the solution obeys water-rights law and economic logic, thereby saving money — and water — in





the long run. How ingrained is ReNUWI's collaborative culture? PhD students in the program must have a core advisor at one of the other universities, Drewes explained.

OTHER BREAKTHROUGH WATER PROJECTS

- Some of the Mines Park bioreactor's effluent is flowing into an onsite greenhouse. Inside, a USDA-funded team led by Mines Professor Christopher Higgins is watering food crops with it, to study plant uptake of pharmaceutical and personal care products such as sucralose, antibiotics and other chemicals that wastewater treatment plants weren't designed to capture.
- Cath has won a \$1.4 million grant from the U.S. Department of Energy to study ways to treat the "produced water" that emerges from hydraulic fracturing operations in natural gas drilling. This involves, as Cath puts it, "taking black, black water and, using membrane technologies, turning it into something usable for the next fracturing operation." For the work, the "AQWATrailer" — a mobile lab with various filters, membranes, pumps and laboratory gizmos — will be called into action, he said. "It allows you to do things on a real scale in the field," Cath explained. "Not many schools have this type of infrastructure."
- The same certainly goes for the wooden wind tunnel circumscribing half of what was once the shallow end of the Volk Gymnasium pool. Its loop is large enough to ride a bike through. With the breeze topping out at about 22 mph, you won't find models of NASA hypersonic vehicles inside — though "it'll blow-dry your hair," quipped Mines Professor Kate Smits. Smits and her team are interested in the interaction of soil moisture and the atmosphere, which remains poorly understood. The wind tunnel lets them adjust the air speed above the soil surface as well as temperature and humidity. The heart of the system is a Plexiglas soil tank sandwich 24 feet long, four inches wide and four feet deep. An array of sensors penetrates and surrounds it, including an anemometer system the Mines undergraduate robotics club built. Researchers fill the translucent tank with soil, enabling the precise assessment of basic physical processes at

a scale larger than lab bench, but more wieldy than a field site. They then build real-world observations into numerical models. One of her research goals is to help climate modelers sharpen their software's accuracy in modeling evaporation rate. She's found, for example, there is a big evaporative difference between a 1 mph wind and a 2 mph wind. But higher winds than that seem to have less of an impact, Smits said. Another application of her work is to increase the ability to accurately detect landmines. The loose soil covering mines and the presence of the mine itself create different thermal and hydraulic properties in the area around the mine, as opposed to a location away from a mine, she explained. "One of the reasons I became an environmental engineer is that I love helping people and helping the environment," Smits said. "With land mines, we can see the potential positive impact we can make by understanding the science."

- Alexis Navarre-Sitchler, a Mines assistant professor, focuses on water-related science hundreds of feet below the surface. Her team's work aims to sharpen the understanding of how acidity affects the amount of lead and other metals in aquifer water. Given the interest of carbon capture and sequestration — pumping carbon dioxide from power plants into formations thousands of feet down — it's a hot topic. Carbonated water isn't the problem (that's what Perrier® is, after all). But greater acidity from leaking carbon dioxide could speed chemical reactions that release lead, uranium and other metals from aquifer rock. In the lab, PhD student Assaf Wunsch bubbles CO₂ through half-liter acrylic cylinders. By determining the mineral content of 23 elements in both the water and the rocks, he can see how different types of aquifers may react to carbon leakage. In related work, Navarre-Sitchler is working on models — run on the Jaguar supercomputer at Oak Ridge National Laboratory — investigating the migration of metals in aquifer.

Like so much of the water-related work happening at Mines, it's science with big implications. As Navarre-Sitchler points out, "You can't accurately understand the risks without understanding the issues."



ANA PRIETO, POST-DOCTORAL RESEARCHER IN CIVIL AND ENVIRONMENTAL ENGINEERING



JOHN McCRAY



Researchers are learning how wastewater could be used to nurture algae, which in turn treats the wastewater. The algae could be turned into useful lipids, biopolymers or even fuel.

Good Fortune Will Be Yours



Craig Barrett delivered the May 2012 commencement keynote address at Colorado School of Mines. In the following excerpt, he shares his insights on how to shape a successful future.

My words of advice are not going to come from the great books of the world. Rather they are going to come from that ultimate source of wisdom — a source that we are all familiar with and consult routinely — a source that I consulted constantly during my 35 years in the high-tech industry — a source that I have never found to be wrong.

That source is the Chinese fortune cookie, and the examples I use come from real fortune cookies that I have come across over the past two decades.

“The world will always accept talent with open arms.”
(From Chef Chu’s in Silicon Valley)

To me that means that education is the key that opens doors of opportunity. With a good education you have the chance to move to the next level — to get into graduate school — to get the job of your dreams — to pursue research interests to help humanity — to start a new business — and if successful, perhaps even to pay back college loans. A good education is just a start, though. It gives you the opportunity to move forward, but to be successful moving forward, you will need to commit to continue learning. In fact, the easy part of your education you are just leaving; the tough part will start in the professional marketplace.

And you will have to have a passion for what you do — that is the talent the world is looking for — a good education along with the love and passion of doing the job at hand. If you have this combination, then I don’t think you can go wrong. Whether you want to be a poet, an engineer, a doctor, a CEO or an entrepreneur, the world will readily accept you if you have the talent. In today’s world we hear a lot about competition between countries, about jobs moving off-shore, about

what professions are safe and which are liable to be exported. I think all these speculations are bogus. What is really important for success is talent, and there will always be opportunity for people with rich talent no matter where they live, and no matter what their chosen profession.

“You cannot win unless you choose to compete.”
(From the Golden Phoenix Restaurant in Phoenix, Arizona)

In today’s world we all know there is increased competition and no entity can rest on its laurels. Just because you were number one yesterday does not ensure that you will be number one tomorrow. The individual worker in the marketplace knows this. Companies know this. But apparently some entities like national and state governments have yet to realize this truth. For example, the United States has the highest GNP of any country and one of the highest standards of living in the world, and is a place where innovation and investments in the second half of the 20th century flourished and greatly added to our national wealth.

Today our country is struggling with this concept of competition. How do we compete with the likes of India and China? How do we create the smart people and smart ideas necessary for 21st century success? Fundamentally we are hampered by the feeling that we have always been number one, and we will always be number one, and we don’t really have to do anything different. I think nothing could be further from the truth. If you want to win, you must choose to compete, and that means doing the things necessary to compete. You cannot just hope that things will get better.

You all know the state of K-12 education in the United States. You know that we have dropped from number one in



Dr. Barrett toured research facilities and talked with faculty during his visit to Mines.

the percentage of our adults with college degrees to about number 13 among the 34 countries in the Organisation for Economic Co-operation and Development (OECD). You know that our investments in R&D have been stagnant for years and are about half of what they were in terms of percent of GDP as compared to an increasing investment stream by our competitors. Soon, as a country, we will have to decide to compete just as you, as an individual, will have to decide to compete if you want to be successful.

“A small deed done is better than a great deed planned.”

(From Kuala Lumpur in Malaysia)

If you think about this for a minute, it seems obvious. Small deeds are done by individuals or small groups — a teacher helping a child, a micro loan made to a struggling entrepreneur in a developing country, a doctor donating time to help the impoverished, a recent graduate joining Teach for America to help children in poor school districts.

All of these are small deeds done. All of these help people. The contrast is the global program. Take, for example, the United Nations Millennium Development Goals — eliminating world hunger or eradication of illiteracy — or the U.S. government efforts to save Social Security or keep Medicare from bankrupting society. These great deeds planned with their lofty goals hardly ever achieve anything. President Kennedy stated this fortune in a slightly different fashion many years ago when he suggested that we ask not what our country can do for us, but what we can do for our country.

Individual actions carry much more importance and impact than great deeds planned.

CRAIG R. BARRETT

Craig Barrett received BS, MS and PhD degrees in Materials Science from Stanford. He was a Fulbright Fellow at Danish Technical University and a NATO Postdoctoral Fellow at the National Physical Laboratory in England. Dr. Barrett joined Intel in 1974, was promoted to president in 1997, CEO in 1998, and chairman in 2005, a post held until 2009.

Dr. Barrett is a leading advocate for improving education and is a vocal spokesman for the value technology can provide in raising social and economic standards globally. He chairs Achieve, *Change The Equation*, Dossia, Skolkovo Foundation Council, Arizona Ready Education Council, and BASIS School, Inc., co-chairs the Lawrence Berkeley National Laboratory Advisory Board, vice chairs Science Foundation Arizona and the National Forest Foundation, is on the Board of Society for Science and the Public, K12 Inc., Arizona Commerce Authority Board, and serves on the Council for Foreign Relations’ U.S. Task Force on Education Reform and National Security. Dr. Barrett served as chair of the U.N. Global Alliance for Information and Communication Technologies and Development, and the National Academy of Engineering, co-chaired the Business Coalition for Student Achievement and National Innovation Initiative Leadership Council, and served on the Board of the U.S. Council for International Business and the Clinton Global Initiative Education Advisory Board.



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