2016-17

COLORADO SCHOOL OF MINES RESEARCH

The Future of 3D MicroMachining

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Preparing the next generation of STEM teachers | PAGE 28

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CONNECTIONS

COLORADO SCHOOL OF MINES

As the song goes, it's been a very good year. Readers will note a common element in this issue of the *Colorado School of Mines Research* magazine—the university's critical connections to multiple stakeholders, including industrial partners, other universities, government entities and national laboratories.

ON CAMPUS

Mines has officially "broken ground" on the CoorsTek Center for Applied Science and Engineering, and Meyer Hall is now but a memory. This fantastic new multidisciplinary facility will serve as the home of the Physics Department, will provide space for a material characterization facility and will serve as a center for the expanding bio-research activities on campus. During construction, physics research is continuing in a newly constructed laboratory that will provide valuable swing lab space once physics moves into its new home.

IN THIS ISSUE

The three feature articles in this issue illustrate both the sophistication and diversity of ongoing research activities on campus.

- Professor Jeff Squier's research on ultra-short pulse lasers has identified an approach to simultaneously focus the beam in space and time. This allows the option of combining imaging with micromachining, with applications ranging from eye surgery to 3D printing on submicron-length scales.
- Mines is leading the way in preparing the next generation of STEM teachers. Partnering with the University of Northern Colorado, we are preparing Mines students to become science and math teachers for grades 7–12. Funded largely by the National Science Foundation, the program aims to help meet a state and national shortage of highly qualified science, technology, engineering and mathematics (STEM) teachers.
- The Gold King Mine spill in Colorado last summer focused the nation's attention on the urgent need to clean up abandoned mines. With its multidisciplinary expertise and collaborative relationships with industry and government, Mines is poised to play a key role.

ALSO OF NOTE

- The Alliance for the Development of Additive Processing Technologies (ADAPT) is dedicated to the development of next-generation data informatics and advanced characterization technologies for additive manufacturing technologies. These tools help industry and government qualify, standardize, assess and optimize advanced manufacturing processes and parts. ADAPT was established in December 2015 through a $1.9 million grant from the Colorado Office of Economic Development and International Trade. Faustson Tool, Ball Aerospace & Technologies Corp. and Lockheed Martin Space Systems provided the initial demand and vision for ADAPT, as well as providing more than $4 million in cost share. The initial research goals include improving nickel-based and titanium-based alloy 3D printing. The R&D in ADAPT is carried out by Mines students and post-docs, directed by assistant professors Aaron Stebner and Douglas Van Bossuyt together with Assistant Research Professor Branden Kappes.

- This year saw the inaugural Innovation Celebration. The Mines Research Office presented the Inventors of the Year award to Professor Kent Voorhees and Research Assistant Professor Chris Cox for their technology of phage and fatty acid detection in pathogens and efforts to move these developments into the marketplace. In addition, several students were recognized for their contributions to Mines' entrepreneurial community, and awards were presented to student groups that had participated in the Newmont Mining challenge. We anticipate an even larger event next year as Mines continues to emphasize both excellence in research and advancing some of these efforts toward commercialization.

- Thanks to the generosity of Bhakta Rath, director of Material Science and Component Technology at the Naval Research Laboratory, the Dr. Bhakta Rath & Sushama Rath Research Award will recognize the Mines PhD thesis with potential for greatest societal impact. Our first awardee is Laura E. Condon of the Civil and Environmental Engineering Department. Her thesis title is "The role of large-scale water management in natural systems: Connections, interactions and feedbacks." Condon was presented this award by Rath at the May 12 graduate commencement ceremony.

As Mines researchers continue to improve and devise new solutions for some of the world's greatest challenges, our collaborative partnerships will remain crucial. One advantage of these connections is the opportunity for Mines students and faculty to access experimental facilities such as X-ray beam lines, neutron sources and other unique technologies. The infographic in this issue (on page 22) illustrates some of the many connections between our researchers and U.S. national laboratories. Currently, such connections account for more than 10 percent of our research funding and serve to demonstrate both the diversity and relevance of our work.

Anthony Dean
Senior Vice President for Research and Technology Transfer

Anthony Dean was appointed senior vice president for Research and Technology Transfer at Colorado School of Mines in January 2015. He was named vice president for research in October 2014 after serving as dean of the College of Applied Science and Engineering from 2012 to 2014. He was the W. K. Coors Distinguished Professor in the Mines Department of Chemical Engineering from 2000 to 2012. Previously, Dean taught in the Chemistry Department at the University of Missouri-Columbia and ran a research group in the Corporate Research Labs of Exxon Research and Engineering.

At Mines he is still active in research. These research efforts focus on the quantitative characterization of reaction networks. Electronic structure calculations are used to develop rate rules and these are employed to develop detailed chemical mechanisms. These mechanisms are applied to a variety of systems, with particular emphasis on the impact of fuel structure on performance and emissions.

In 2008, he received the Dean's Excellence Award at Mines. In 2012, Dean received the Colorado Section Award from the American Chemical Society. He received his B.S. in chemistry from Spring Hill College and his AM and PhD in physical chemistry from Harvard University.

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RESEARCH

On the cover: Mines PhD student Nathan Worts views a representation of spatial frequency modulation for imaging (SPIFI) masks he machined into glass.

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

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FEATURES

Deirdre D. Keating

MINES

COLORADO SCHOOL OF MINES | AT A GLANCE

Colorado School of Mines, situated in Golden, Colorado, is a highly selective, public research university offering bachelor's, master's and doctoral degrees in engineering and applied sciences. ■ Mines is internationally recognized for its education and research programs focusing on stewardship of the earth and its resources, developing advanced materials and applications, addressing the earth's energy challenges, and fostering environmentally sound and sustainable solutions for the world's greatest challenges. ■ Through its three colleges and 14 academic departments, Mines enrolls 5,924 undergraduate and graduate students (as of fall 2015) and conducts more than $60 million in sponsored research. ■ Learn more at mines.edu.

EPA awards $1.95M for stormwater treatment technology research

Aging water-infrastructure systems and regulatory requirements are making storm water management an expensive challenge for many communities. As water flows through storm drains, it carries pollutants that end up in streams, rivers, ponds, lakes and oceans. In addition, combined sewers carry sewage and stormwater runoff in the same pipe, and when these exceed capacity, untreated water can be released into nearby waterways.

To help with this issue, the U.S. Environmental Protection Agency (EPA) has granted Colorado School of Mines $1.95 million to develop a tool to help communities evaluate the optimal mix of technologies that will treat stormwater with less energy, less expense and less burden on the environment.

"Our decision-support tool will help advance urban water management across the U.S. through integration of new green infrastructure technologies and by allowing decision makers to have access to state-of-the-art tools, data sources and life-cycle information," said Mines Professor Terri Hogue, lead investigator.

The tool will evaluate options and risks as well as life cycle costs associated with improving storm water runoff management using green, gray and hybrid infrastructure. Mines will also create resources and hold workshops to conduct training sessions for these tools.

Deirdre O. Keating

Harvesting water from asteroids

Mechanical Engineering Assistant Research Professor Christopher Dreyer and Director of the Center for Space Resources Angel Abbud-Madrid have been awarded NASA grants to work on an out-of-this-world extraction technique called optical mining.

Optical mining will use concentrated solar energy to heat and fracture asteroids, causing them to release volatile elements. These resources will be extracted and used in space to avoid the high cost of transporting them from Earth.

"We are contributing experimental evidence for the conditions under which intense light will disassemble carbonaceous chondrite asteroids," Dreyer said.

The project is funded by a $500,000 grant from the NASA Early Stage Innovations program and a $125,000 grant from the NASA Small Business Innovation Research program.

Mines researchers are working in this multidisciplinary effort with Missouri University of Science and Technology Professor Leslie Gertsch (Mines alumna GE '82, PhD '89) and TransAstra Corp. Founder and Principal Engineer Joel Sercel. The University of Hawaii also is participating in the project.

3D metal printing consortium established

STEBNER

VAN BOSSUYT

Mechanical Engineering Assistant Professors Aaron Stebner and Douglas Van Bossuyt were awarded a $2.5 million Advanced Industries Accelerator grant from the Colorado Office of Economic Development and International Trade to establish a 3D metal printing research consortium. Industry partners Lockheed Martin, Ball Aerospace, Faustson Tool and Manufacturer's Edge are providing more than $4.5 million of initial investment in the program.

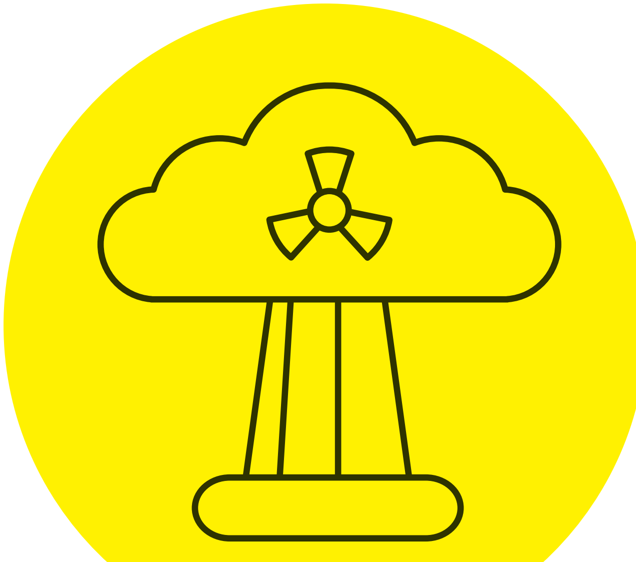
The center will be dedicated to performing applied research and creating database infrastructure needed to qualify 3D printers and their parts in a timely, cost-effective manner. Large businesses will be able to rely on the center to help accelerate their technology-development cycles, while small manufacturing businesses will be able to supply certified 3D printed metal parts to advanced industries.

Some of the highlights of the program are two U.S. firsts: 1) Mines will perform research together with Faustson and Concept Laser on the first U.S. installed dual-laser 3D metals printer—a technology that will reduce manufacturing times; and 2) Mines also will acquire the first U.S. university-owned X-ray diffraction microscope capable of both diffraction contrast tomography and submicron-resolution computed tomography for purposes of advanced microstructure characterization of 3D printed metal parts.

Over a 12-month period, Mines researchers will demonstrate the capabilities of the center's infrastructure through two pilot research projects on 3D printed nickel and titanium alloys. The research performed in the consortium will benefit five advanced industries: advanced manufacturing, aerospace, bioscience, energy and natural resources (including clean technology), and infrastructure engineering.

The center also will offer workforce-training programs at Mines and other Colorado institutions so students can have access to the facility and research opportunities.

With support from this funding, together with the undergraduate curriculum pioneered by Van Bossuyt, Mines anticipates graduating more than 100 students proficient in additive manufacturing each year.



Analyzing nuclear detonations

TREWYN

BRALEY

Mines researchers are developing radiation-resistant porous materials for the rapid and robust separation of f-elements for the analysis of post-detonation debris. Chemistry and Geochemistry Assistant Professors Brian Trewyn and Jenifer Braley were awarded a $750,000 grant from the Defense Threat Reduction Agency (DTRA) to support their research on post-detonation nuclear forensics efforts.

"This research could potentially make a significant leap forward in the area of rare earth elemental separations and capitalize on advancements in the field of material science," Trewyn said. "It will further our understanding of the interactions of rare earths with functionalized mesoporous materials."

Materials developed in this research will help provide information about a given nuclear detonation, particularly the type of device—atomic bomb or hydrogen bomb—that was used.

DTRA is an agency within the U.S. Department of Defense and is the official Combat Support Agency for countering weapons of mass destruction, including chemical, biological, radiological, nuclear and high explosives weapons. DTRA's main functions are threat reduction, threat control, combat support and technology development.

National Academy of Engineering Center for Engineering Ethics and Society honors three Mines programs

In its report "Infusing Ethics into the Development of Engineers," the National Academy of Engineering Center for Engineering Ethics and Society showcases 25 engineering programs at colleges and universities that are exemplary in their approach. Colorado School of Mines was the only university to receive three awards. The Mines programs and associated faculty are:

- **Corporate Social Responsibility Course:** Jessica Smith, Hennebach assistant professor, division of liberal arts and international studies (LAIS)

  "As I teach it, corporate social responsibility empowers students to practice engineering within corporations in a way that also promotes the social, environmental and economic well-being of communities and other stakeholders. This kind of training has become increasingly important as we see the energy and commodity markets shifting so significantly before our eyes, raising new questions about how corporations, employees and communities manage their relationships with one another during downturns," said Smith.
- **Nature and Human Values Course:** Sarah Hitt, Teaching Associate Professor, LAIS

  "We utilize faculty expertise from multiple disciplines and use real-world ethics scenarios to explore the social, cultural, political and environmental aspects of science and engineering, which prepares students to excel in their academic, professional and civic life," said Hitt.
- **Enacting Macroethics:** Making Social Justice Visible in Engineering Education: Jon Leydens, Associate Professor, LAIS; Juan Lucena, Professor, LAIS; and Kathryn Johnson, Associate Professor, Department of Electrical Engineering and Computer Science

  "Working against disciplinary silos, our [Leydens, Lucena and Johnson's] multicourse, multidisciplinary approach emphasizes identifying interplays between technical and social dimensions of engineering problem defining and solving. This collaboration is a clear example of how rigorous, technical courses like Feedback Control Systems always have social dimensions that, if rendered visible, can lead students to see how the engineering curriculum connects with social justice," Leydens said.

The programs described in the report all clearly connect ethics to technical engineering curriculum and conduct assessments of their programs, both of which were criteria for submission.

PRODUCT DEVELOPMENT

Mines fire extinguishers sent to space

Angel Abbud-Madrid

Water-mist portable fire extinguisher inspected before launch at NASA Johnson Space Center.

Angel Abbud-Madrid

The Mines and ADA Technologies team after the final test of the water-mist portable fire extinguisher. From left: Tyler Grubb, Thierry Carriere, Angel Abbud-Madrid, Michael Tomlinson, Michael Krysiak and John Maloney.

A space payload designed and tested with the help of Colorado School of Mines faculty and students was successfully launched to the International Space Station on Dec. 6 on the Orbital ATK OA-4 mission aboard a United Launch Alliance Atlas V rocket.

After several years of research, testing and conducting experiments on a variety of NASA flight facilities (including drop towers, low-gravity aircraft and a space shuttle experiment in 2003), the Mines team found water-mist fire-suppression technology to be more efficient and suitable for putting out spacecraft fires than any other suppression agent.

"Water-mist systems create a fog of micron-size droplets that quickly remove heat and replace oxygen as the water evaporates, suppressing the fire and preventing it from spreading to other surfaces," said Director of the Center for Space Resources Angel Abbud-Madrid. "From the space shuttle experiments, we also learned that water mists take about one-tenth the water of traditional sprinklers to extinguish a flame."

The research on this project began in 1997 in an effort to find an environmentally friendly replacement for harmful chemical fire-suppression agents for terrestrial and space applications. After these encouraging results, Mines partnered with Littleton-based ADA Technologies to develop several prototype water-mist portable fire extinguishers for spacecraft applications. Mines and ADA collaborated with three NASA centers (Johnson, Glenn and White Sands) to design and test the spaceflight units. Wyle Engineering and Flexial Corp. then fabricated and certified all portable fire extinguishers for flight.

As it becomes the preferred fire-suppression agent for the space station, these water-mist portable fire extinguishers will protect the equipment and lives of astronauts from fire for years to come.

Mines breaks ground on CoorsTek Center for Applied Science and Engineering

Officials from CoorsTek, the Coors family and Colorado School of Mines broke ground on the new CoorsTek Center for Applied Science and Engineering, an interdisciplinary academic and research facility, in May 2016.

The CoorsTek Center will support Mines' College of Applied Science and Engineering and will be the home of the Department of Physics. It will serve as an integral campus landmark located on the site of the former physics building, Meyer Hall, at 15th and Arapahoe streets. Completion is expected in spring of 2018.

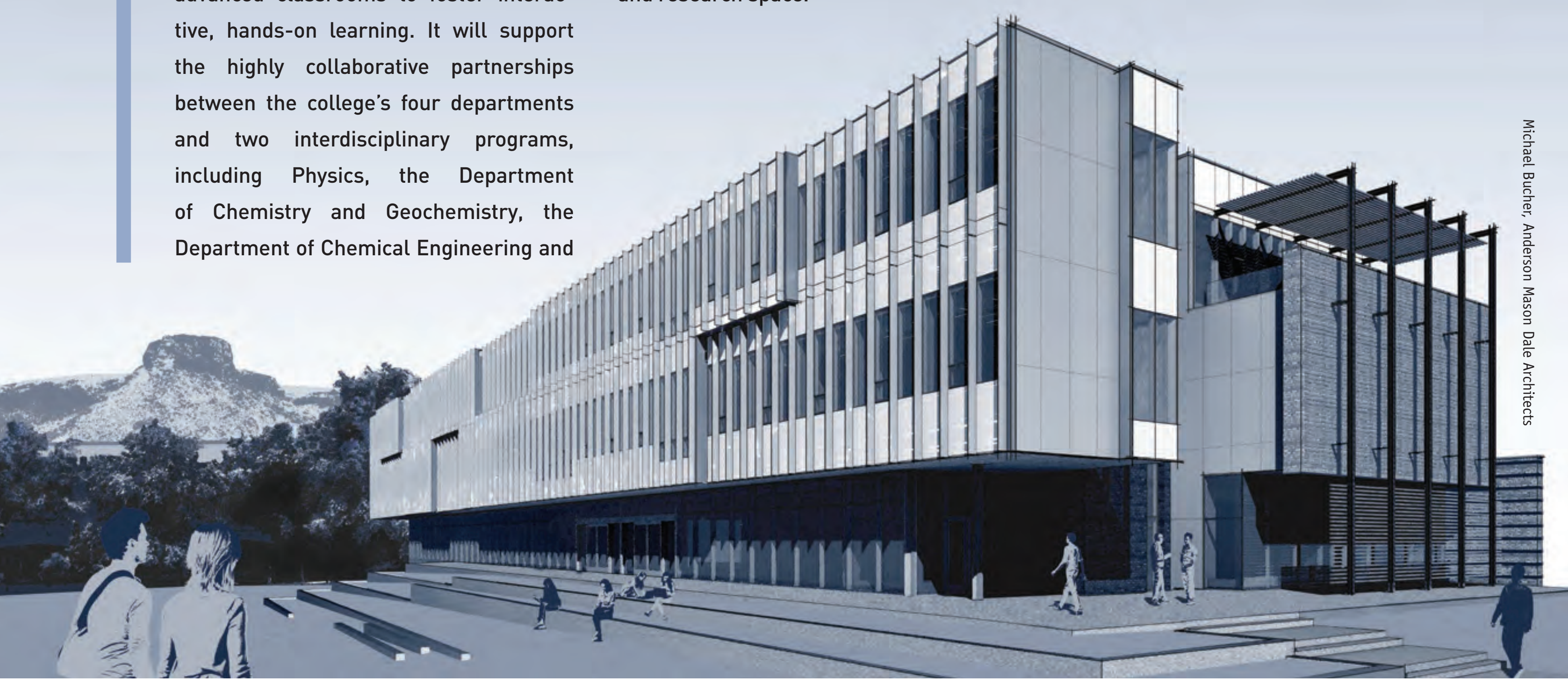
The nearly 100,000-square-foot building will feature forward-thinking design with flexible lab space and technologically advanced classrooms to foster interactive, hands-on learning. It will support the highly collaborative partnerships between the college's four departments and two interdisciplinary programs, including Physics, the Department of Chemistry and Geochemistry, the Department of Chemical Engineering and Biological Engineering, the Department of Metallurgical and Materials Engineering, the Materials Science Program and the Nuclear Science and Engineering Program.

In 2014 CoorsTek and the Coors family announced a $27 million commitment to fund a research partnership and the construction of this facility. The investment is a significant milestone in the multigenerational partnership between CoorsTek and Mines.

Internationally renowned architecture firm Bohlin Cywinski Jackson, in partnership with Denver-based Anderson Mason Dale Architects, has designed the modern, $50 million centralized teaching and research space.

Kathleen Morton

CoorsTek CEO John Coors and Mines President Paul Johnson break ground on the new CoorsTek Center for Applied Science and Engineering.



Michael Bucher, Anderson Mason Dale Architects

Laurie Schmidt

Mines-led study yields insight on age of groundwater across the U.S.

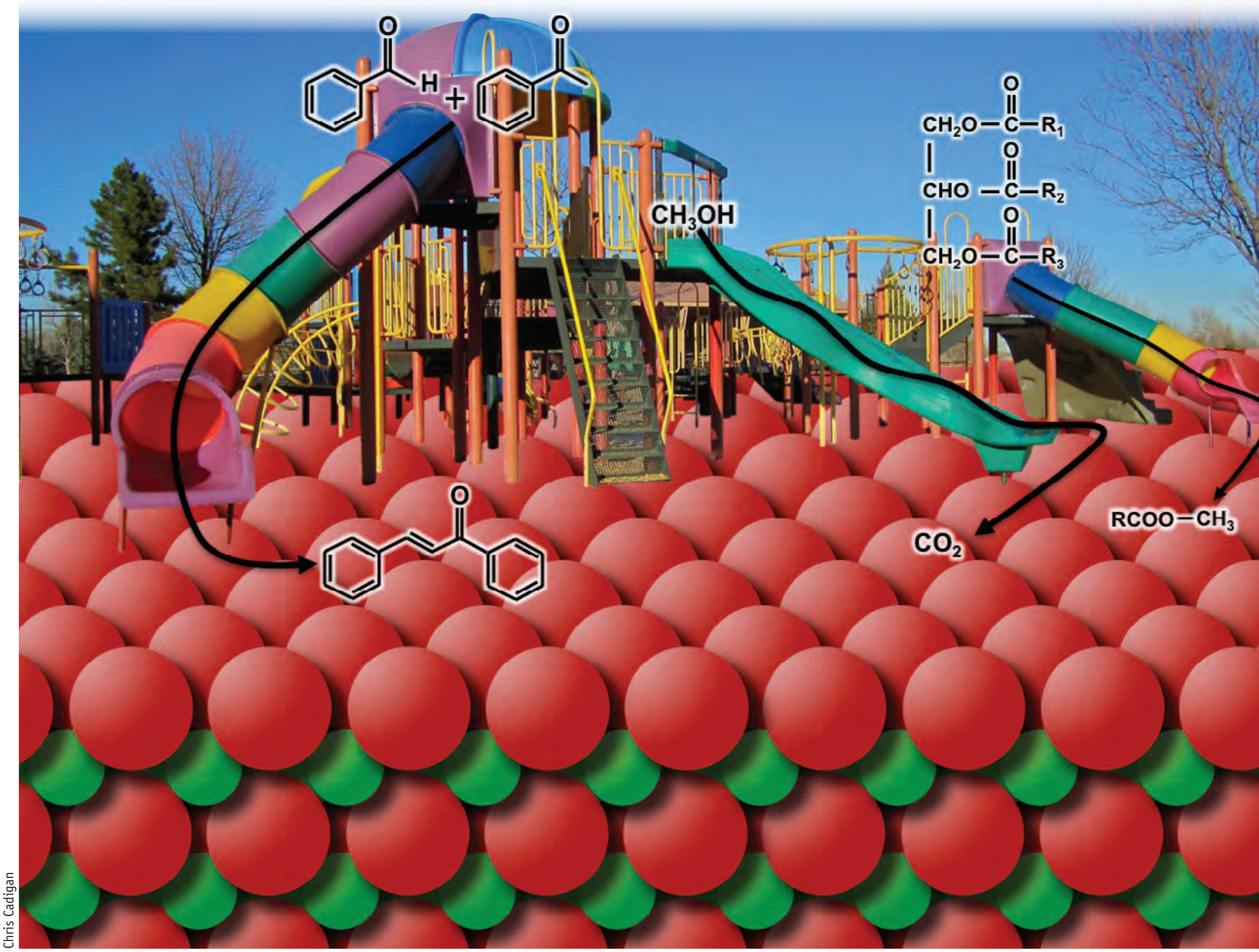
A Colorado School of Mines-led study, recently published in the journal "Geophysical Research Letters," lends insight into how long it takes for rain or snow to move into a river or stream. The study helps inform scientists' understanding of timing and persistence of water over the major basins of North America.

Mines researchers—along with colleagues from Syracuse University, Stanford, Oregon State and Bonn University—used computer models to predict and understand the residence times of groundwater over the major basins, including the Mississippi and Colorado rivers. They found that water in streams can be anywhere from days to thousands of years old.

"Results of the modeling showed that the geology of the subsurface controlled the peak time for water to make its journey while aridity controlled the spread of ages," said Reed Maxwell, professor of hydrology and director of the Integrated Groundwater Modeling Center at Mines. "This helps us better understand timing and persistence of things like contaminant transport, but also how plants have nutrients to grow, how clean the water is and even things like how rock weathers to become soil over scales we have never been able to tackle before."

Maxwell noted that the time elapsed between a precipitation event or snowmelt and water's arrival in a river governs flow and storage, while also moderating water for human use and ecosystem function. Previous work has shown that water may take from months to thousands of years to make this journey. Yet these so-called residence times are difficult to directly observe and have to be inferred from radioactive-bomb fallout or carefully measured in small research watersheds.

These findings can guide where and how we observe our earth and highlight the need for future modeling studies and stream contribution observations to explore relationships among water age, soil and rock type, and aridity.



Chris Cadigan

Change agent

Catalysis is one of the most important processes in the world, and collaborative efforts at Mines aim to make it more efficient

We speak of presidential candidates as "catalysts for change." We know we have a catalytic converter in our car. But few people understand just what the word means, or how vital catalysis—the acceleration of a chemical reaction via a specialized material, or catalyst—is for supporting life, fueling the economy and building a sustainable future. Colorado School of Mines Chemistry Professor Ryan Richards wants to change that.

Richards hopes to help build Mines, the National Renewable Energy Laboratory (NREL) and Golden, Colorado, into a national hub of catalysis research in the coming years. He notes that 35 percent of the gross world product (GWP), from gasoline and jet fuel to plastic, is made using catalytic processes; 40 percent of the population is sustained by fertilizers produced via catalysis. As the global population grows and energy demands increase, it's critical for scientists to come up with new catalytic materials that are more abundant, cheap and efficient. That's where Mines—with its multidisciplinary focus on earth, energy and environment—and its neighbors at the Golden-based NREL, come in.

"It's about bringing all of these people with different teaching and research backgrounds together with a common goal to work on society's biggest problems," said Richards.

Look around you and you'll see that you're surrounded by the benefits of catalysis. Inside your car, a catalytic converter made of precious metals like palladium and rhodium converts the toxic pollutant carbon monoxide into carbon dioxide and transforms smog-forming gases into more benign emissions. (Its advent in the mid-70s is credited with improving air quality in many U.S. cities). At every petroleum refinery, a catalyst helps turn crude oil into gasoline or plastic. The game-changing Haber catalytic process, developed in the early 20th century, uses an iron catalyst to convert nitrogen from the air into ammonia for fertilizer. In the renewable energy world, everything from fuel cells to biomass technologies hinges on catalytic materials that help turn input A into energy source B with as little waste as possible.

The problem, explained Richards, is that many of today's catalysts are made with scarce and expensive metals. Take platinum. "It takes between five and 10 tons of mined ore and five months of processing to get one ounce of platinum, and all of that is located in Russia and South Africa," Richards said. "We need to find ways to use things that are more earth-abundant instead, like iron, copper and nickel, and we need to teach them how to do new tricks."

To do this, Richards collaborates with computer and materials scientists at Mines, and researchers from NREL. Using high-throughput computational screening, Mines Professor Christian Ciobanu identifies elements that might, if manipulated or mixed just the right way, have the electronic and physical properties to make a good catalyst. Richards and colleagues act as chefs, using nanotechnology and other means to develop that novel material. (They recently devised one highly promising catalytic material made with plentiful metal carbides and nitrides.) Then NREL steps in.

"They do the discovery science and then hand it off to us so we can apply it, evaluate it and bring it to the cusp of commercialization," said biomass researcher Josh Schaidle, platform manager for NREL's Thermochemical Catalysis Research and Development group. "It's a great synergy between fundamental science and applied science."

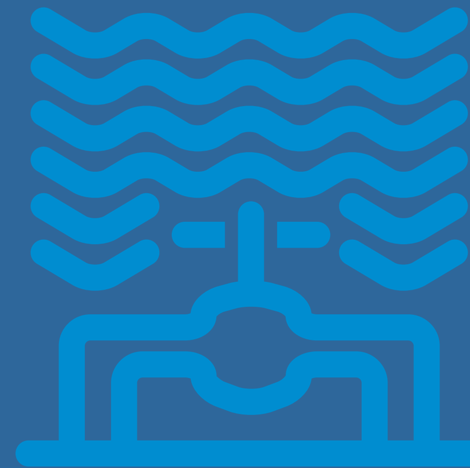
Schaidle said improving the availability, affordability and efficiency of catalytic materials could go a long way in making renewable energy sources more competitive with petroleum-derived fuel and thus more widely used.

For instance, economic analysis of one new catalyst composition in development found that its use could reduce the cost of biomass-derived fuel (made from renewable feedstock like corn husks, forest residue or construction waste) by a full dollar per gallon. "That is a huge change. It highlights just how important the catalyst step is for the entire process," said Schaidle.

The same goes for fuel cells, which tend to contain catalysts made from expensive platinum. "If you could significantly reduce your platinum load (via new catalyst designs or materials), it would give you a much greater potential for market penetration," Schaidle said.

In December, Schaidle and Richards hosted a catalysis workshop to bring together dozens of local experts in the area and plan new ways to boost research and collaboration in Golden. Within the next few years, Richards envisions a number of new classes at Mines (many of them hinged around catalysis and renewable energy), a new Mines website devoted to catalysis research and a new Golden-based catalysis institute that will integrate the researchers involved and raise the overall visibility of this group to students, colleagues and industry.

"This is the ideal time to do this" he said, "and this is the ideal place to make it happen."



DOE awards $1.5M for geothermal research

Deirdre O. Keating

Mines Civil and Environment Professor Tzahi Cath has been awarded a $1.5 million grant from the U.S. Department of Energy Geothermal Technologies Office to study membrane distillation desalination of impaired water using low-grade heat from geothermal power plants.

The grant is part of a three-year, $4.8 million project led by the National Renewable Energy Laboratory in collaboration with Sandia National Laboratories, University of California, Riverside, General Electric and Ormat.

Geothermal resources and water scarcity are common features of the western United States. Within this region, low-temperature (<100 °C) geothermal resources have wide geographic distribution but are highly underutilized because they are inefficient for power production.

A potentially useful application of low-enthalpy geothermal energy, from low-temperature resources or rejected heat from high-temperature geothermal power plants, is the desalination of impaired waters.

Cath's research focuses on water and wastewater treatment and reuse.

Seeing in the dark: Mines researchers are developing new ways to light the way for tunnel boring machines

Imagine driving your car down a mountain road, at night, without headlights.

That's what underground construction is like, said Mike Mooney, the Grewcock Distinguished Chair and Professor of Underground Construction & Tunneling at Mines. Massive, multimillion-dollar tunnel boring machines (TBMs) are chewing through rock and soil deep beneath the ground's surface with little sense of what lies ahead—including boulders, building foundations or underground voids that could cause a surface collapse or an inrush of water.

Students and faculty in Mines' Center for Underground Construction & Tunneling are working to turn the lights back on by developing technologies that image ahead of TBMs.

Tunneling without imaging is risky. "There's a great need to see ahead because the geology is highly uncertain," Mooney explains. "And if we're tunneling in urban environments, which is often the case, we're under buildings with underground foundations, utilities, old buried structures. There's a chance you could hit one of those, which could be very damaging to the TBM and the structures on the surface."

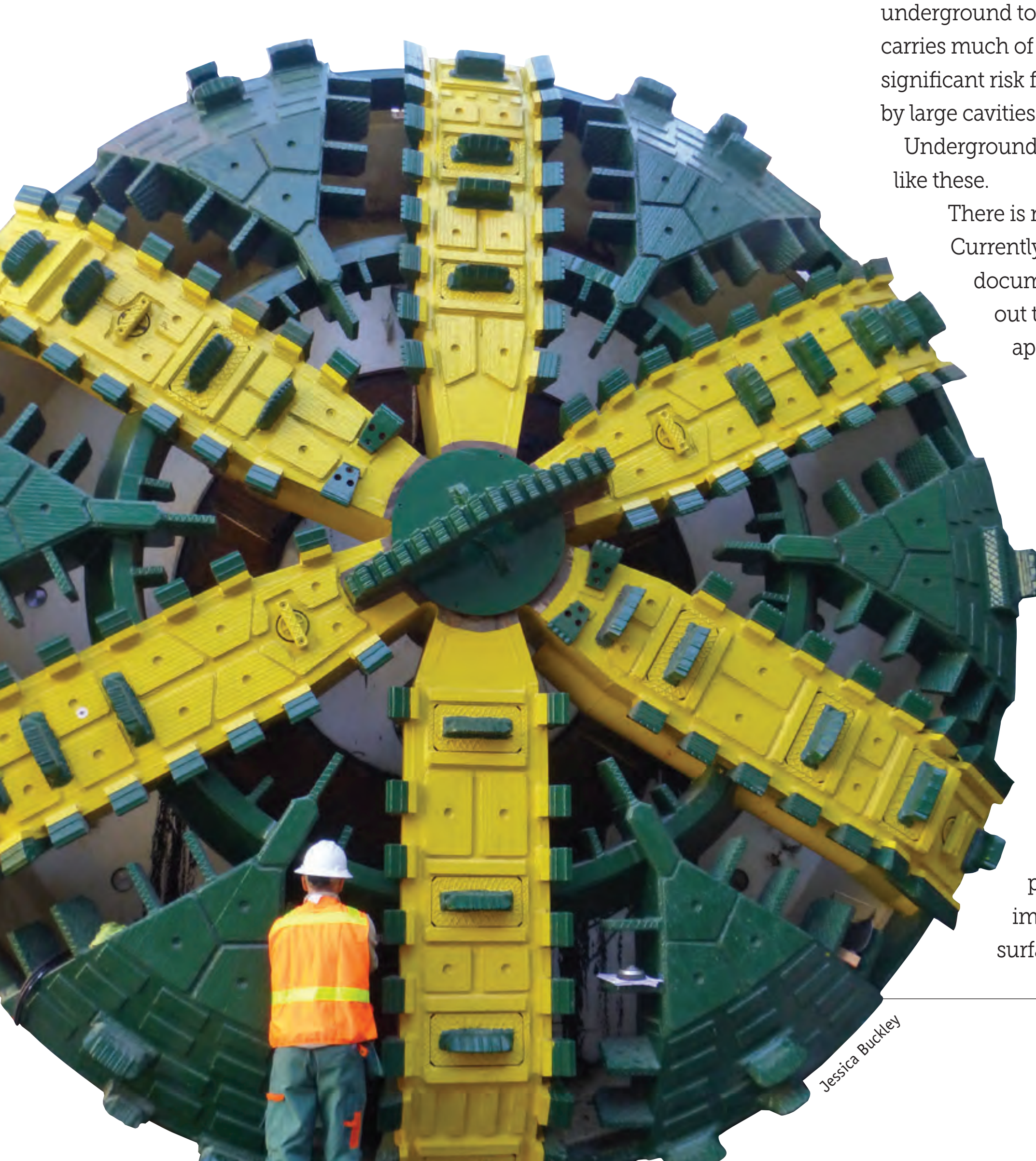
That's what happened in December 2013 when the TBM "Bertha" was excavating a highway tunnel under Seattle. It struck a buried pipe no one knew was there, and tunneling was stopped for two years. In New York, tunneling will soon begin 900 feet underground to repair the leaking Delaware Aqueduct, which carries much of New York City's water supply. That project faces a significant risk from high-pressure groundwater inflows caused by large cavities in the limestone.

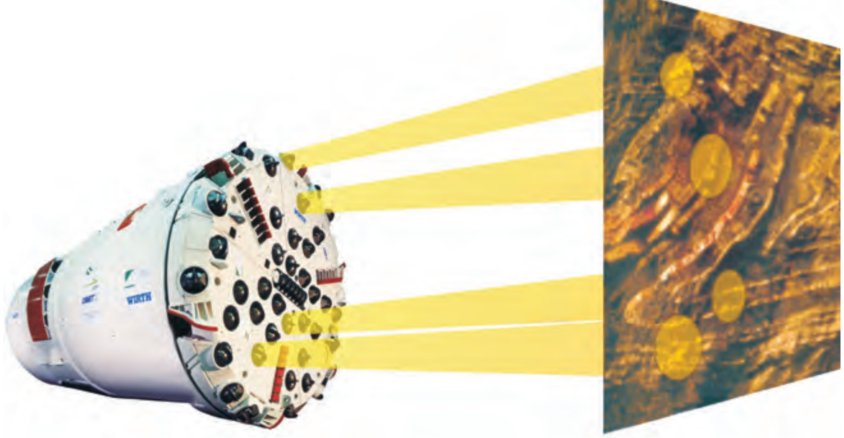
Underground look-ahead technology could prevent scenarios like these.

There is no reliable way to image in front of TBMs. Currently, "Underground areas in urban areas are not well documented," Mooney said. "There is no silver bullet out there for how to do this—no industry-accepted approach."

Typically, vertical boreholes are drilled to assess underground conditions prior to design and construction. But 4- to 6-inch diameter boreholes sunk every 300–500 feet don't paint a complete picture. "Abrupt changes in geology, faults and seams that are conduits to water can be the most damaging and are very difficult to assess," Mooney said. "It's not economical to turn the ground into Swiss cheese using boring techniques, so we need completely different ways of going about it."

Mooney said the most promising solution relies on measuring the electrical resistivity and conductivity of subsurface structures—a technique that's been in use for nearly a century, primarily in oil and gas exploration. But electrical imaging techniques typically are deployed at the surface or through boreholes. The challenge in





Geo Exploration Technologies

Diagram of Bore-tunnelling Electrical Ahead Monitoring (BEAM).

applying it to underground construction is integrating it into an enormous, moving machine. "The TBM is a big, conductive body," Mooney said. "It can have a significant influence in the electrical current injection and field. That's a big obstacle to overcome."

And, Mooney adds, "Some things in the ground are easier to image than others. A metal pipe is easier to image than a boulder; a large boulder is easier to image than a small boulder." Mooney's team, including civil engineering PhD candidate Kevin Schaeffer, started exploring tunneling-imaging applications five years ago as part of Mines' interdisciplinary SmartGeo program.

They began with laboratory testing in a large sandbox with TBM scale models. That eventually led to complex computational modeling, which demonstrated that the TBM imaging system can see ahead 40–180 feet, depending on the size of the boring machine and the anomaly of interest. If data is analyzed in real time, that should be enough of a look ahead to prevent trouble.

The research has been funded by a five-year, $3 million National Science Foundation grant and a gift from Kiewit Construction CEO Bruce Grewcock, a 1976 Mines alumnus, that helped launch the interdisciplinary Center for Underground Construction & Tunneling.

The next phase of research includes field testing in Seattle, where center researchers are planning to install sensors on a TBM digging a subway tunnel. Mooney also is hoping for a field test in Los Angeles, where casings of abandoned oil wells dot the underground landscape and pose a particular hazard for a subway expansion.

"One of the biggest challenges we face in underground construction is that we don't exactly know what lies ahead," Mooney said. "As we move to more and more building underground, if we can solve that problem, then we enable a huge leap forward for that industry."

Boulder buster

As researchers at Mines' Center for Underground Construction & Tunneling have been exploring techniques to produce underground images ahead of tunnel boring machines (TBMs), they've also developed a solution for a particular obstacle looming underground: Boulders.

If a TBM is moving too quickly when it hits one of these large boulders—resistant artifacts of glaciation that can be as big as a VW Bus—it can significantly damage the machine and stop a project cold. In Seattle, tunnel borers have been moving through glacial deposits as they dig two subway passages and an underground highway. To detect boulders at the first possible moment—when there's still a chance to prevent damage—center researchers recently instrumented the subway TBMs with accelerometers, which detect and monitor vibration in rotating machinery.

"The second the cutting-face cutting wheel begins to graze a boulder, it creates a vibration that we developed an algorithm to detect," the center's Mike Mooney explains. "It alerts the operator; then the operator can back off on the torque and thrust."

Tunnel builders can't go around the obstacle, but they can go through it if they adjust correctly. "If we hit a boulder when we're going fast and keep trying to go fast, the boulder will break the [cutting wheel] teeth," explains Mines alumnus Glen Frank, construction manager for Seattle subway tunnel builder JCM Northlink. "If you try to take a big bite of the boulder, the tooth breaks. If you take a little bite, the boulder breaks." Previously, Frank explains, TBM operators would ride standing in what's known as the shield, a section just behind the cutting face. They could feel vibrations when they hit boulders and adjust accordingly. But today's TBMs are more complex and there's no longer room for the operator at the front; instead, the operator rides in a cab that may be trailing hundreds of feet behind, where they can't feel impact vibrations.

That makes a boulder-detection system critical.

Funded by the National Science Foundation and Jay Dee Contractors, a leading underground construction firm, Mooney developed the boulder-detection system with Mines graduates Bryan Walter and Jessica Buckley.

"We can detect when we're hitting boulders. It's definitely telling us what we want to see," Frank said. "Now we need to integrate it into the machine and the training to allow us to use the new technology efficiently."

Intelligent geosystems

In a new application of a time-tested technique, Mike Mooney, civil engineering PhD student Rick Bearce and geophysics post-doc Pauline Kessour have incorporated electrical resistivity imaging into a probe that instantly measures the diameter of in-ground mixed soil-cement columns. Mines has filed a patent application for this solution to an enduring challenge in the construction industry.

Making next-gen biofuels more viable for U.S. military

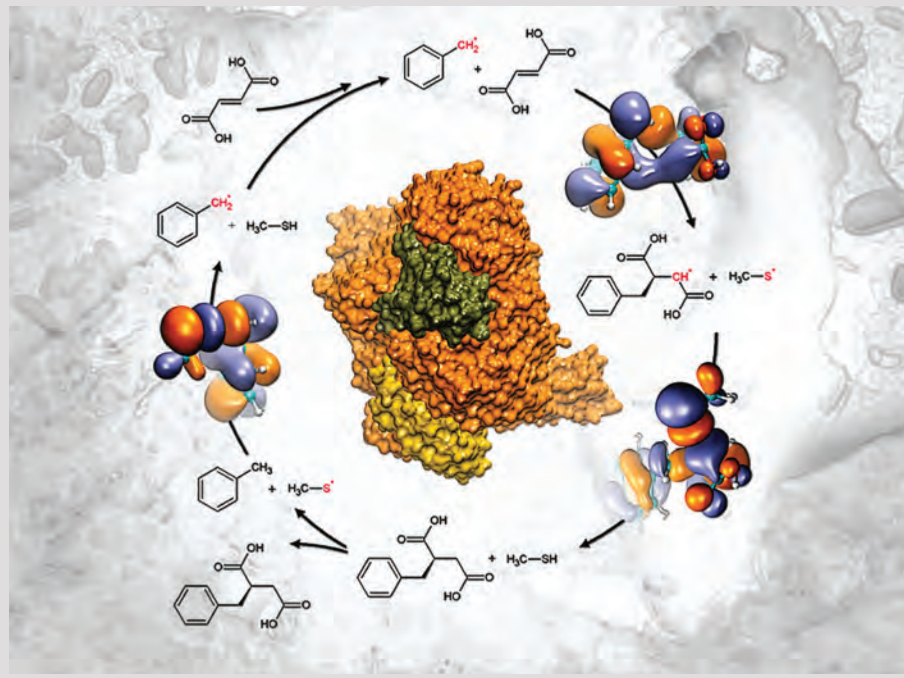
MAUPIN

The U.S. Navy aims to generate 50 percent of its energy from alternative sources by 2020—this includes nuclear energy, electricity from renewable sources and biofuels. This goal can only be met, said Mines Assistant Professor Mark Maupin, "if we can surmount some daunting issues."

Maupin is working to make the use of biofuel more viable for the U.S. military, particularly the Navy, with help from undergraduate and PhD students.

First of these is the fact that microorganisms found in nature—and essentially every fuel storage tank and pipeline—will consume both petroleum-based liquid fuel and biofuels using them as a primary carbon source. Although the loss of fuel itself is not the biggest problem, Maupin said, "The microorganisms can cause the fuel to go 'bad,' and the presence of the microorganisms and the associated biofilms they produce are linked to corrosion of the fuel storage containers and pipelines."

The Navy has already had a serious issue with microbial-induced biocorrosion in their compensated fuel-ballast tanks, leading to costly maintenance, and is concerned about the impact of new biofuels on the rate of storage tank corrosion.



Maupin, his former PhD student Vivek Bharadwaj, and Anthony Dean, vice president for research at Mines, are part of the Office of Naval Research Multidisciplinary University Research Initiatives team looking into the problem, focused particularly on the ability of microorganisms to use biofuels as food. The Mines group also included two undergraduate students who have worked in Maupin's lab over two consecutive summers via Research Experiences for Undergraduates funding, Nathaniel Eagan and Nicholas Wang.

The group's work was first featured in the "Journal of the American Chemical Society" in 2013, focusing on one of the first steps that microbes take to digest the fuel. Using two enzymes, benzylsuccinate synthase and alkylsuccinate synthase, the microbes turn the fuel into something they can use as a building block for molecules such as fatty acids. The paper details the first creation of a homology model for one of the enzymes and provides molecular-level insights into the mechanism behind this reaction, which adds a fumarate molecule to the fuel.

A second paper, published in the journal "Physical Chemistry Chemical Physics" in February 2015 and featured on its back cover, looked at the impact of different hydrocarbon structures on the energetics and kinetics of the fumarate addition.

Maupin's group was most recently published in the journal "Chem Phys Chem" and featured on the inside cover for a separate but related project. The paper details the work they've done to evaluate certain properties of biodiesel, which is made up of fatty acid methyl esters (FAMEs), the primary component in biodiesels.

A typical biodiesel created from algae or other lipid sources is actually composed of different types of FAMEs, varying in carbon tail length and the amount of double bonds in the tail. These variations impart various properties on the liquid fuel, such as density, viscosity, diffusion rates, crystal-formation characteristics and cloud point. Maupin and his team have been simulating different FAMEs and multiple biodiesel mixtures to identify the components necessary for creating desired characteristics in the fuel.

Using microscopy in renewable energy and life sciences studies

Faculty in the Department of Chemical and Biological Engineering are creating a self-sustaining, scanning-probe microscopy facility with unique capabilities for advanced materials research, thanks to a $245,878 grant from the National Science Foundation.

Professor Colin Wolden and Associate Professor Keith Neeves have acquired an atomic force microscope and coupled it with an optical microscope for simultaneous imaging and nanoscale-level measurement of physical properties. Materials will be studied primarily for renewable energy and life sciences applications.

The facility's unique feature will be the ability to measure the electrical and mechanical properties of materials in direct registry with topography at nanoscale resolution, under the conditions they will be used (e.g., under light for photovoltaics, or in hydrated conditions for biological materials).

The facility will be open to departments across Mines, as well as regional partners including the National Renewable Energy Laboratory and Children's Hospital Colorado. Wolden and Neeves will organize and host an annual Rocky Mountain Scanning Probe Microscopy Workshop to provide training opportunities and attract new regional users. Undergraduate students will be introduced to the facility through Mines' existing summer Research Experiences for Undergraduates programs.

Mines, NREL developing low-cost-of-energy wind turbine

Colorado School of Mines Electrical Engineering and Computer Science Associate Professor Kathryn Johnson, who also holds a joint appointment as a scientist at the National Renewable Energy Laboratory (NREL), was one of six researchers who received a $3.56-million grant from the U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) to develop a low-cost-of-energy 50-MW turbine. The small-scale design will produce more than six times the power output of the largest current turbines, be longer than two football fields and have blades that resemble a palm tree.

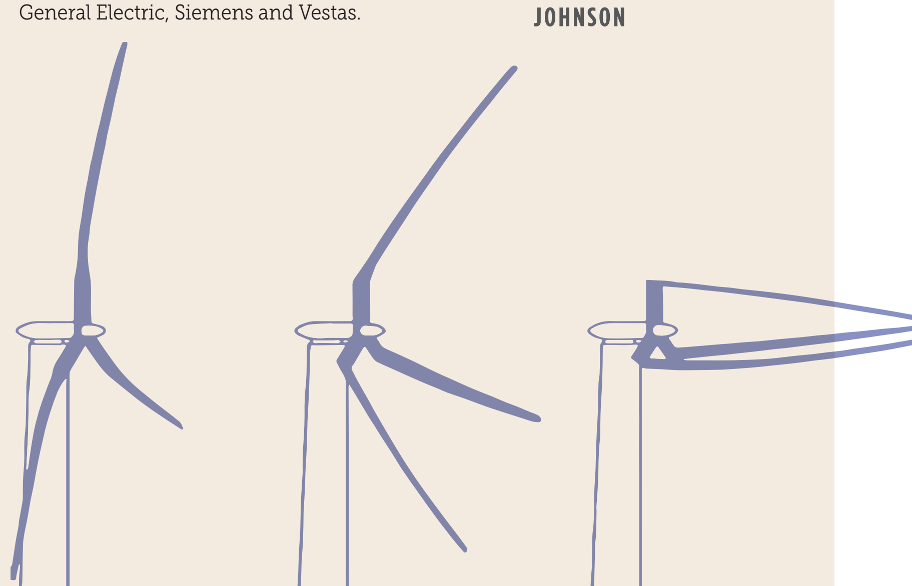
"Palm trees bend in the wind easier than a harder, stiffer tree," said Johnson. "That means they are less likely to snap in high winds, so these blades will be able to bend out of the wind and therefore will put less stress on all the other turbine components. You will be able to put these turbines in places that have higher wind conditions."

In the next two years, Johnson will be working with graduate student Dana Martin to create computer simulations that will test the prototype turbine in various wind conditions. They will examine and manipulate how the turbine operates in response to each of these conditions and how much electricity it produces. Then they will help the team to design and build a prototype for field-testing.

In 2018, the team will build a scale model at NREL's National Wind Technology Center. Johnson and Martin will replace the blades on an existing 600-kilowatt turbine with their scale design. "It will be fun to watch our prototype spin in the real world and look at the data and see what things need to be changed."

The team is led by the University of Virginia and includes researchers from the University of Illinois, the University of Colorado, the National Renewable Energy Laboratory and Sandia National Laboratories. Corporate advisors include Dominion Resources, General Electric, Siemens and Vestas.

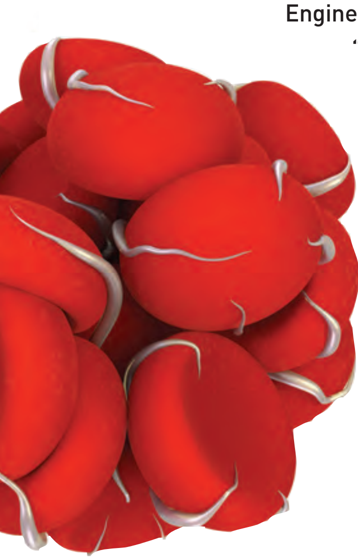
JOHNSON



Injectable microwheels: Fast, effective treatment for blood clots

Mines biomedical microwheel research demonstrates microscopic devices shaped like wheels can be injected into the body and effectively "roll" to treat areas in need—such as arterial blockages.

"Propulsion at the microscale is akin to swimming though molasses, a challenge biomedical microbots must overcome," said Chemical and Biological Engineering Department Head David Marr. "The microbots may either mimic microorganisms using flagella or employ artificial methods to direct themselves. Inspired by our shift to cars from animal-based transport, we show that microwheels the size of a single cell can be constructed and powered with magnetic fields."



Marr notes the devices could be assembled using a "ship in a bottle" approach: injected into the body and then assembled into wheels that roll like car tires to the afflicted tissue using low-strength external magnetic fields. The resulting microwheel movement occurs with greatly improved speeds and directional control compared to other propulsion strategies.

The research, "Surface-enabled propulsion and control of colloidal microwheels," was published in "Nature Communications" and co-authored by Marr, Associate Professor Keith Neeves, post-doc Onur Tasci and Associate Professor Paco Herson of the University of Colorado-Denver.

NSF CAREER Award winners

TOBERER

Physics Assistant Professor **Eric Toberer** has received an NSF CAREER Award for research that could ultimately yield the next generation of thermoelectric materials.

The project, titled "Control of Charge Carrier Dynamics in Complex Thermoelectric Semiconductors," has been awarded $625,000 and seeks to understand the factors that determine the efficiency of certain materials in converting heat into electricity.

According to the abstract, "The goal is to combine recent advances in structural determination and first principles calculations, in concert with single crystal growth and advanced transport measurements, to yield deep insight into charge transport through the careful integration of these measurements."

The development of advanced thermoelectric materials could have a significant impact on the nation's energy portfolio, through solar thermoelectric generators, cogeneration and waste heat recovery. A deeper understanding of charge transport in complex semiconductors also will advance other applications, such as transparent conductors, photovoltaic materials and power electronics.

Toberer joined Mines in 2011. He earned a BS in chemistry from Harvey Mudd College and holds a PhD in materials from the University of California, Santa Barbara.

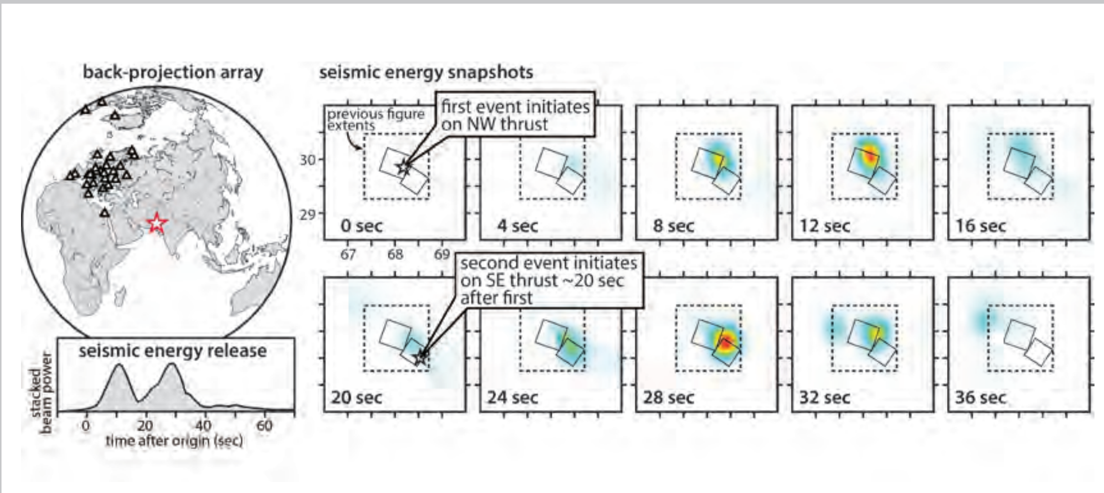
BRENNECKA

Metallurgical and Materials Engineering Assistant Professor **Geoff Brennecka** has received an NSF CAREER Award to study how ferroelectric materials—crystalline materials with a built-in polarization that can be reversed under an electric field—respond to this stimulus at a more fundamental level.

The project, titled "SusChEM: Dynamic Defect Interactions in Ferroelectrics," will receive $458,000 over five years. It will be integrated into Brennecka's efforts to expand student engagement, including participation in the annual Discover STEM Camp at Mines and establishment of a hot glass shop in Hill Hall. It will also fund a graduate student who will work for several weeks each year with collaborators in Virginia and Australia.

Brennecka joined Mines in 2014 and also is a member of the Colorado Center for Advanced Ceramics faculty. He holds BS and MS degrees in ceramic engineering from Missouri S&T and a PhD in materials science and engineering from the University of Illinois at Urbana-Champaign.

Mines study reveals earthquakes can jump



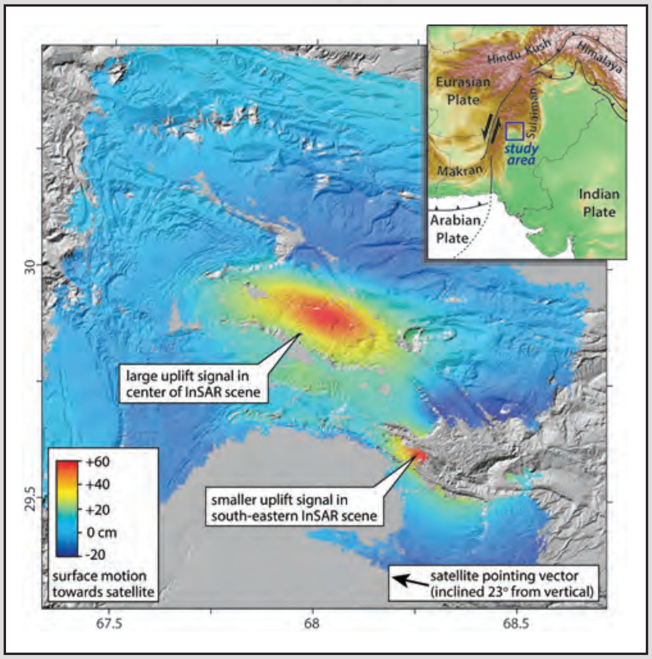
Edwin Nissen

While studying a 7.1-magnitude intracontinental earthquake that occurred in Pakistan in 1997, Assistant Professor of Geophysics Edwin Nissen, along with other researchers, discovered that earthquakes can "jump" between faults, a concept that was not previously thought possible.

"Remote sensing and seismological observations of a recent earthquake in Pakistan highlighted an unexpected incidence of an earthquake rupture 'jumping' across a large gap between two faults," said Nissen. "This has important implications for how we anticipate the size of future earthquakes, a significant question for the half the U.S. population (and for several hundred million people worldwide) who are at risk from damaging seismic shaking."

The earthquake was listed in published seismic catalogs as a single event, but surface deformation mapped using "before" and "after" satellite radar images revealed two large zones of uplift, generated by slipping on two distinct faults. Meanwhile, seismograms show two large pulses of seismic energy, spaced just 20 seconds apart, in the same location as the radar uplift zones.

"The size of an earthquake depends on the length of the faulting involved, and modern earthquake hazard assessments are based on the premise that ruptures are restricted to closely spaced segments and cannot jump between widely spaced ones. Our observations indicate that earthquakes can do just this. In this example, the earthquake doublet greatly increased the duration and area of maximum shaking and probably contributed to the relatively large death toll due to the earthquake," Nissen said.



This image shows ground deformation in the earthquake doublet mapped by differencing radar images captured before and after the event (a technique called InSAR). Red areas moved toward the satellite in the earthquake, whereas dark blue areas moved away from the satellite.

Research connections: Mines and

Developing solutions to the world's challenges

The number of projects represented is current as of May 2016.

Idaho National Laboratory

3

Reducing Actinide Production Using Inert Matrix Fuels

Impact of Atomic Ordering on Long-Term Structural Stability

BEHAVIOR OF BINARY ALLOYS

Pacific Northwest National Laboratory

1

COMPUTATIONAL DESIGN OF IMPROVED STEELS

Lawrence Berkeley National Laboratory

1

HIGH-RESOLUTION REACTIVE TRANSPORT MODELING

Lawrence Livermore National Laboratory

2

WATER AND CLIMATE CHANGE

NIFFTE Time Projection Chamber Project

Jet Propulsion Laboratory

3

JPL Insight Mars Lander Project

ELECTRONIC STRUCTURE ENGINEERING IN SKUTTERUDITE THERMOELECTRICS

Planetary Heat Flux Simulator

COLORADOSCHOOLOFMINES

42+ Grants and Projects

Los Alamos National Laboratory

5

CENTER FOR INTEGRATIVE MATERIALS JOINING SCIENCE FOR ENERGY APPLICATIONS

CO_2 MIGRATION IN 2D TANK EXPERIMENTS

Strengthened Steels for Nuclear Reactor Applications

Advanced Steel Research and Development

Advanced Non-Ferrous Structural Alloys

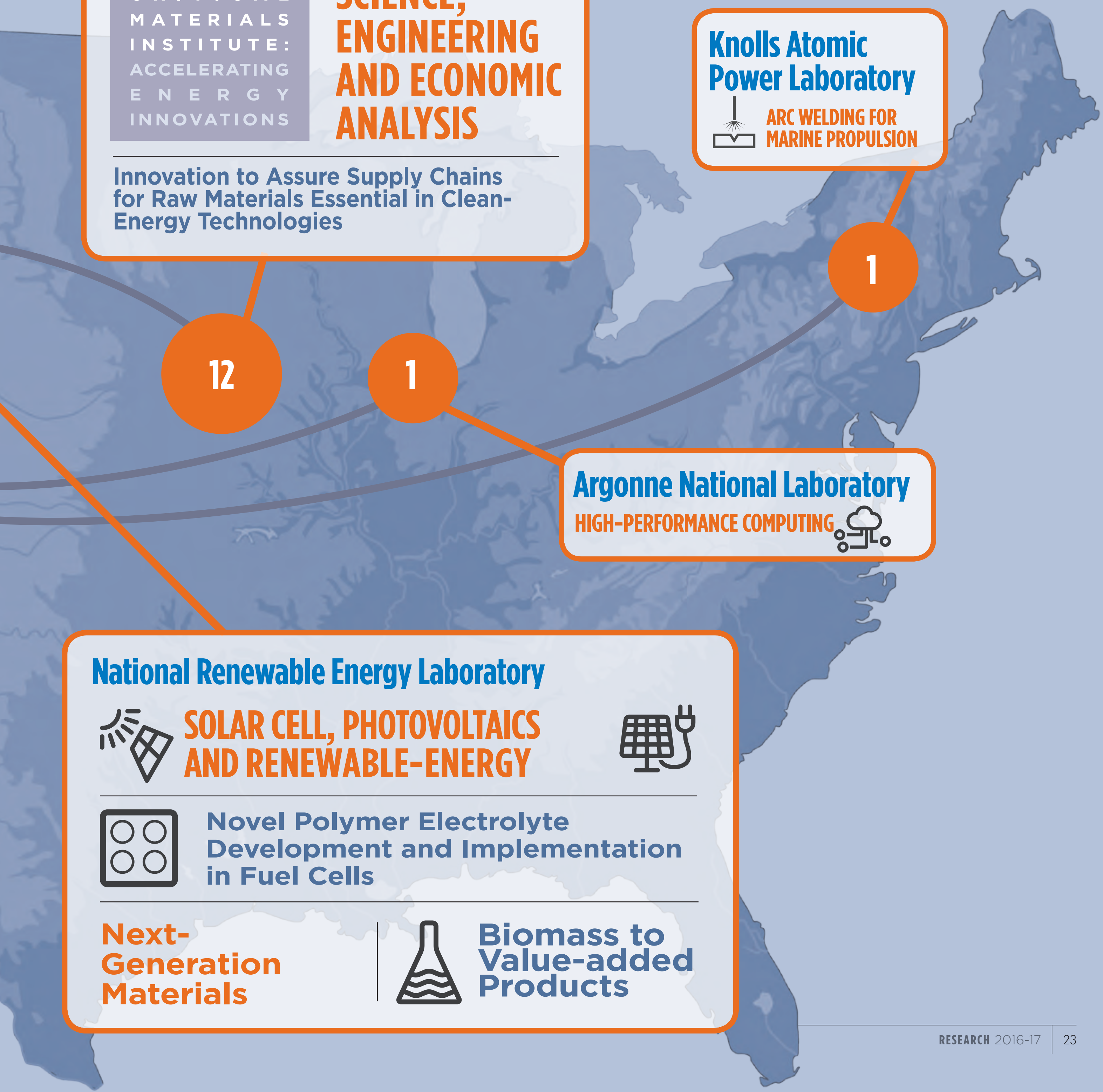
Sandia National Laboratories

2

PREDICTING EXTREME BATTERY RESPONSE

Converting Solar Radiation to Chemical Fuels

the U.S. National Laboratories



Ames Laboratory

CRITICAL MATERIALS INSTITUTE: ACCELERATING ENERGY INNOVATIONS

SCIENCE, ENGINEERING AND ECONOMIC ANALYSIS

Innovation to Assure Supply Chains for Raw Materials Essential in Clean-Energy Technologies

Knolls Atomic Power Laboratory

ARC WELDING FOR MARINE PROPULSION

Argonne National Laboratory

HIGH-PERFORMANCE COMPUTING

National Renewable Energy Laboratory

SOLAR CELL, PHOTOVOLTAICS AND RENEWABLE-ENERGY

Novel Polymer Electrolyte Development and Implementation in Fuel Cells

Next-Generation Materials

Biomass to Value-added Products

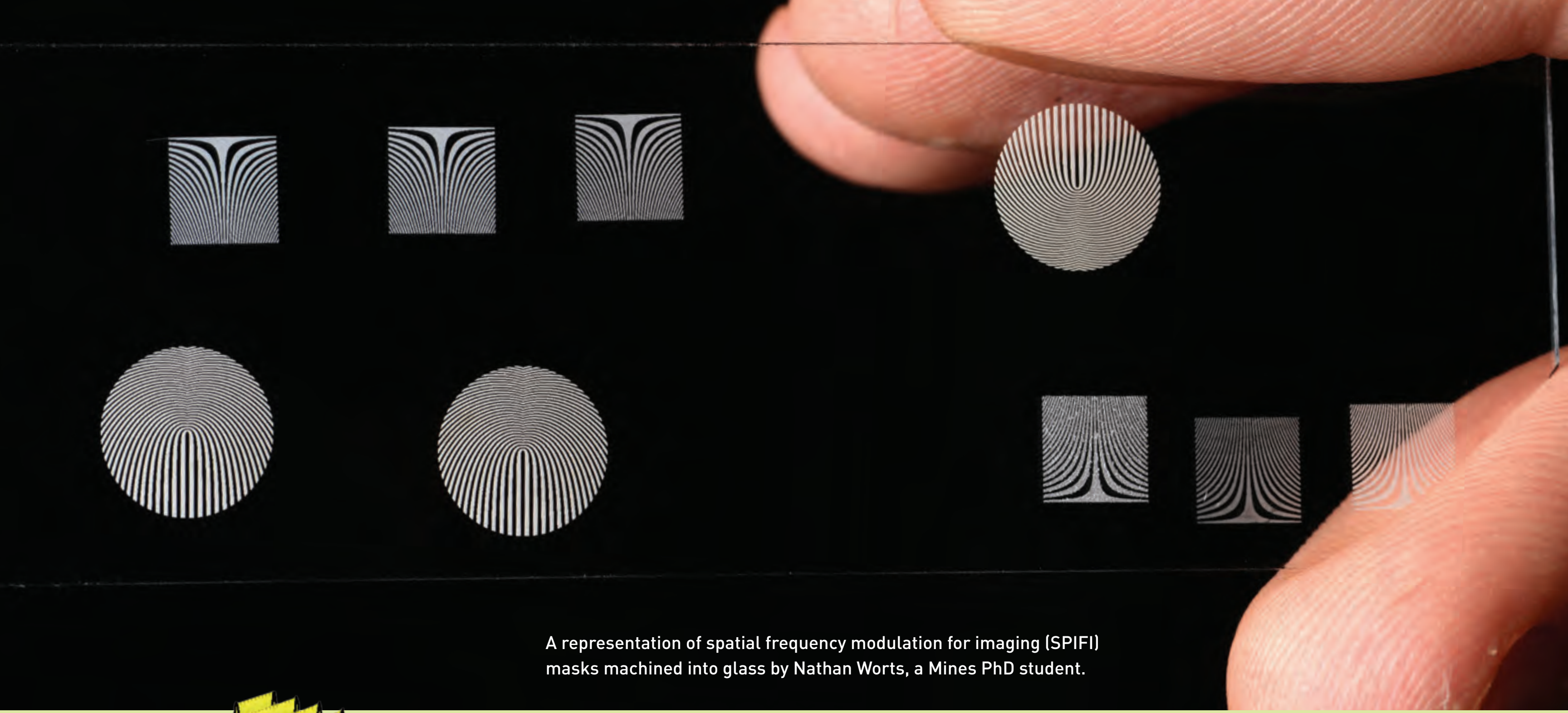
Seeing as machining

A single team in the basement of the Mines General Research Laboratory has advanced the state of the art in what might seem two very different realms: machine tools and microscopes

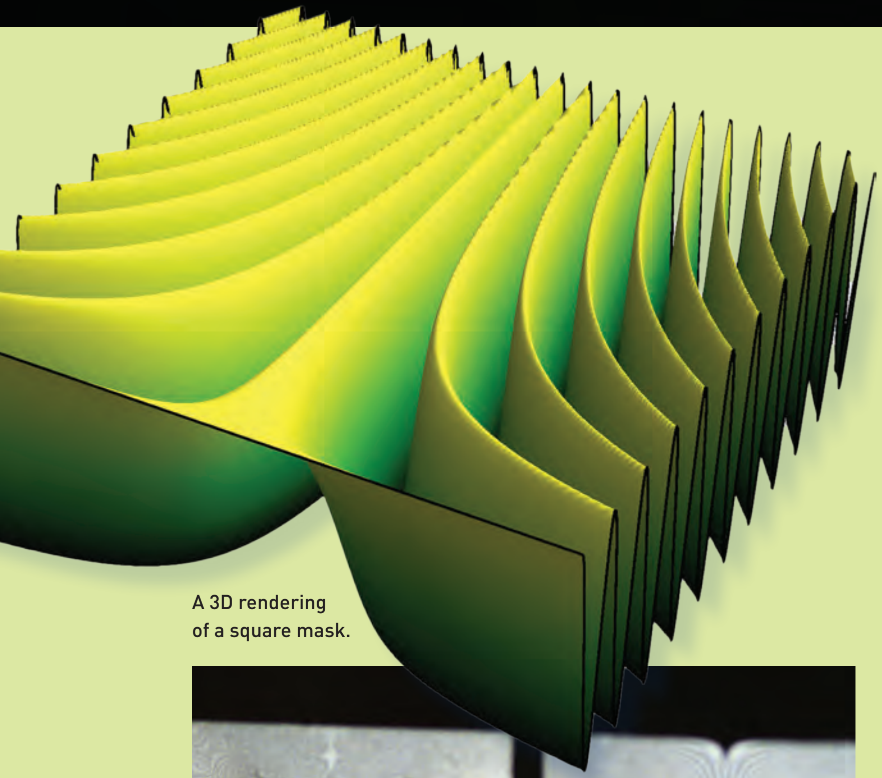
These aren't your typical saws, lathes and presses—and it's far from your average microscope. Jeff Squier and his team do their machining with lasers, and they have combined a microscope of their own design into a single system that promises to improve everything from eye surgery to 3D printing, and at the tiniest scales.

Squier, a Mines professor and chair of the Department of Physics, leads a group whose system combines ultrafast-laser micromachining with microscopy capable of observing and guiding the laser's work in real time. They have broken new ground in both disciplines to enable a unified system capable of cutting, shaping and transforming across a wide range of dimensions deep inside translucent materials while observing and guiding the process.

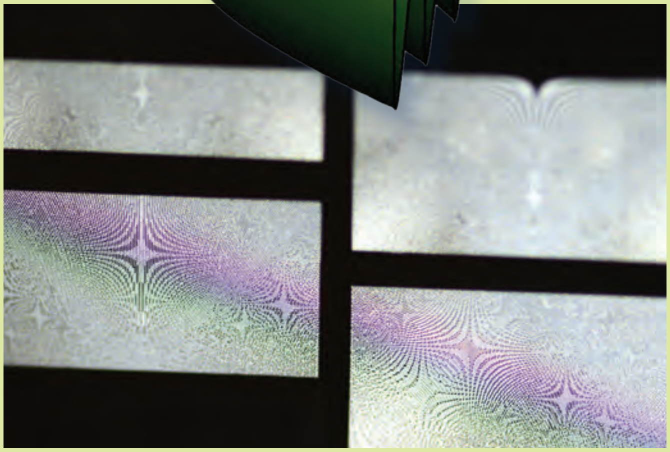
"We're combining the imaging with the machining for the first time," Squier said. "That's really powerful."



A representation of spatial frequency modulation for imaging (SPIFI) masks machined into glass by Nathan Worts, a Mines PhD student.



A 3D rendering of a square mask.



Although it's built on a technological foundation Squier has been pioneering since the late 1980s, the system hinges on two innovations, each the topic of a 2015 Mines PhD dissertation. The first is simultaneous spatial and temporal focusing (SSTF) of the ultrafast laser. The second is spatial frequency modulation for imaging (SPIFI) on the microscope side.

SSTF is a twist on the chirped-pulse amplification (CPA) systems Squier has advanced for decades. Such systems use a series of lenses, gratings, amplifiers, compressors and other optical hardware to stretch out and then recompress femtosecond laser pulses in ways that enable them to machine, ablate or transform targets at submicron scales. (A strand of human hair is about 30 microns in diameter; 100 femtoseconds is about how long it takes light to travel that distance.) Current applications include machining optical waveguides or diffraction gratings, making biomedical stents, carving microfluidic channels and ablating thin films for displays or solar applications.

The CPA-based manipulation of laser pulses is critical because femtosecond lasers squeeze so much energy into their pulses that amplifying them directly would damage the system itself.

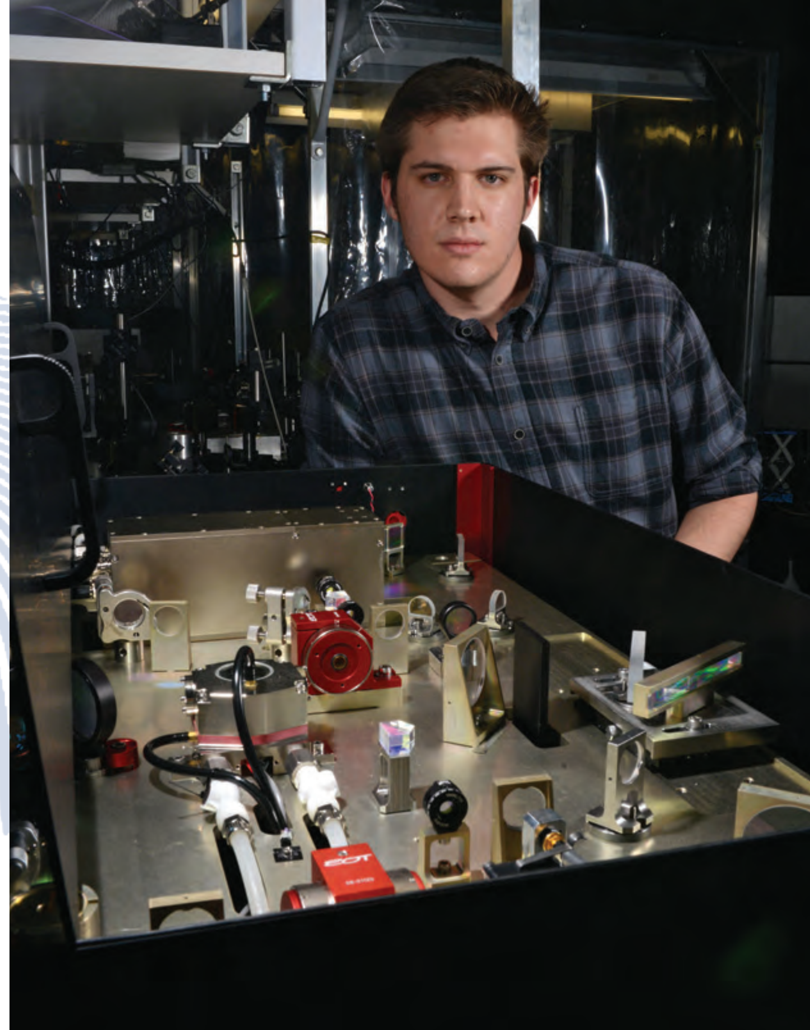
"Peak power goes up so fast, you'd literally just drill holes in everything," Squier said.

But even with CPA, ultrafast laser machining has been limited by its own power. These lasers damage everything between the final aperture and the ultimate target. There are many cases—eye surgery, for example, or etching optics deep inside glass—where this would be detrimental. SSTF is a solution.

Erica Block, now a postdoctoral researcher at Mines, spent years working with Squier to develop SSTF, which was the basis of her dissertation. The basic principle is familiar to anyone who has focused sunlight with a magnifying glass. Close to the glass, the light remains diffuse; at the focal point, its white-hot confluence burns holes in leaves.

While a great deal more complicated, SSTF works by the same principle, using a lens to focus different laser wavelengths such that they overlap again precisely at the focal point. Rather than burning

"SPIFI will never match the resolution of an electron microscope, Young says. But electron microscopes are killers; SPIFI can function harmlessly in a human eye."



Mines PhD student Nathan Worts sits behind a KMLabs laser.

a channel all the way to the target, one can carve, ablate, etch and machine 3D shapes into the core while keeping the periphery pristine. Classic femtosecond-laser micromachining can have no such lens because, as Squier put it, "the laser beam would machine the lens."

SSTF's incorporation of this lens opened the door to integrating a laser microscope with the micromachining system. Michael Young defended his Mines PhD on the microscopy technique he developed to exploit the SSTF lens the week after Block defended hers. Rather than photos of the microscope itself, which occupies a Mines GRL lab next door to the one hosting the SSTF system, his dissertation's cover slide featured a vintage fighter jet loaded with missiles.

"Back in the late 1960s and 1970s, the technology that they had at the head of those heat-seeking missiles is the technology we use to make an image," said Young, now a postdoctoral research fellow on Squier's team.

Well, sort of. Young's SPIFI system starts out using the same femtosecond laser source as the SSTF's machining setup, but in Young's case, it's an engine for wide-field two-photon excitation fluorescence (TPEF) microscopy, to which he added a feature based on, but decades more advanced than, the old heat-seeking missile technology.

Young started work on the first version soon after earning his Mines undergraduate degree in December 2008. He faced the challenge of building a microscope capable of observation at different machining depths, at a high frame rate and at adequate resolution. Young came up with a system featuring a single-pixel sensor and a spatial light modulator—a striped mask called a frequency-modulation reticle, like the ones that spun in the center of missiles.

In this case, the mask was digital, a spatial light modulator built by Boulder Nonlinear Systems, which is supporting Young's fellowship. Light falls on the single pixel differently depending on where it passes through the mask, less on the outside, more in the center. In the ballistic manifestation, the rocket steered toward the light. The microscope uses it to help paint a picture. The image can be centimeters wide—Young has a high-res SPIFI copy of his daughter—or it can be a micron wide. SPIFI will never match the resolution of an electron microscope, Young says. But electron microscopes are killers; SPIFI can function harmlessly in a human eye.

Mines PhD student Nathan Worts is now working to advance Block's micromachining system using an SSTF that KMLabs of Boulder, Colorado, built (the company has also licensed the technology). It compresses a research system occupying dozens of square feet into a box the size of a large suitcase. Meanwhile, Young is enhancing the microscope's resolution with new lenses and other off-the-shelf components. It's a marriage that Squier expects to be fruitful.

"The spatial scales we can address, the broad number of materials we can address, and the fact that we're looking at surgical tools and 3D prototyping—the application base is huge," he said.

Nicholas Dyer, a Mines student in the Mines-UNC STEM teacher prep program, works in a Golden High School classroom.

In a groundbreaking collaboration, Mines and the University of Northern Colorado have launched a program to educate STEM teachers

A meeting of minds

A high school teacher sparked Amanda Casner's passion for physics. "Physics is a cool way to explain the universe!" Casner said. "I was so fascinated with physics, it left me wanting to learn more."

So she enrolled at Colorado School of Mines, where she planned to earn a PhD and go on to a career as a college professor. Along the way, the junior engineering physics major discovered something unexpected: She didn't actually want to teach at the college level.

"I wanted to be more hands-on with students and less in a laboratory," she realized, "and high school would involve more actual teaching."

Casner made that discovery in a presentation by Kristine Callan, a physics teaching associate professor at Mines. She was plugging the new Mines-University of Northern Colorado STEM Teacher Preparation Program, a groundbreaking collaboration between the two universities to prepare Mines students to become science and math teachers for grades 7–12. Funded largely by the National Science Foundation, the program aims to help meet a state and national shortage of highly qualified science, technology, engineering and mathematics (STEM) teachers.

Casner isn't alone in her interest in teaching. "There are a number of students who like science and math in high school and come to Mines thinking they need to be an engineer," said Renee Falconer, a Mines teaching professor of chemistry. "They get here and realize they still like math and science but don't want to spend their career that way.

"This is a way they can still be involved in science and math without being an engineer," she added. "Every single teacher we put out affects the lives of thousands of kids and improves their attitudes about science and math."

Before the teacher prep program's founding, there was no easy alternative for Mines students like Casner who wanted to become teachers. They would have had to transfer to another institution altogether or complete their Mines degree and then attend a post-baccalaureate program somewhere else.

"There's a huge body of prepared students at Mines," said Wendy Adams, director of science education programs and associate professor of physics, natural and health sciences

at the University of Northern Colorado (UNC). "By giving them a straightforward option to become teachers, we can really impact the state's need for math and science teachers."

That need includes close to 300 math and science teachers in Colorado and thousands more across the nation.

Disproportionately affecting rural schools and those serving low-income and minority students, it's a shortage some have identified as a crisis with implications for the nation's competitiveness in the global market. In 2011, President Barack Obama announced a goal to prepare 100,000 STEM teachers within a decade. Mines has joined some 200 other partners in the 100Kin10 coalition, which is leading the nation's efforts to meet that goal.

Close to home, a new strategic initiative by the Colorado Department of Education aims to position Colorado as a national leader in growing a local talent pipeline by "ensuring all learners have the STEM education and experiences needed to succeed in an innovation economy."

Mines-UNC Teacher Preparation Grants

2014 | **$299,720**
Collaborative Research:
An Engineering University Partnering with a Teacher Preparation University to Produce Highly Qualified Secondary STEM Teachers
National Science Foundation, Robert Noyce Scholarship Program Capacity Building Grant

Colorado School of Mines
Principal Investigator: Gus Greivel
Co-Principal Investigator: Renee Falconer
Senior Personnel: Kristine Callan, Steven DeCaluwe, H. Vincent Kuo

University of Northern Colorado
Principal Investigator: Robert Reinsvold
Co-Principal Investigators: Wendy Adams and Christy Moroye

2015 | **$319,504**
Collaborative Physics Teacher Preparation at University of Northern Colorado and the Colorado School of Mines
Physics Teacher Education Coalition PhysTEC Grant

University of Northern Colorado
Principal Investigator: Wendy Adams
Co-Principal Investigator: Christy Moroye

Colorado School of Mines
Principal Investigator: H. Vincent Kuo
Co-Principal Investigator: Kristine Callan, Steven DeCaluwe

2016 | **$1,199,978**
Collaborative Research and Teacher Preparation Program Leveraging the Strengths of a Research University and a Premier Teacher Preparation University
National Science Foundation, Robert Noyce Scholarship Program

Colorado School of Mines
Principal Investigator: Kristine Callan
Co-Principal Investigator: Renee Falconer

University of Northern Colorado
Principal Investigator: Christy Moroye
Co-Principal Investigator: Rob Reinsvold
Senior Personnel: Wendy Adams

In Jefferson County—Mines' own backyard—a growing STEM workforce demand is driving an increasing interest in and need for STEM education. "We're trying to create as many different pathways as possible to engage student learning, to try to connect with every single kid so they have a successful pathway to graduation," said Ryan West, director of Choice Programs for the district. "STEM is an important part of that."

According to UNC's Wendy Adams, it's not just the number of STEM teachers that matters. Quality counts, too. "We always hear about the perception of teaching as a second choice. We need to put our best and brightest in the classrooms," she said, noting that many of the nation's best and brightest can be found at Mines.

Students like Casner, who aims to be among ranks of new STEM teachers who are both excellent teachers and excellent scientists. She enrolled in the teacher prep program in summer 2015 and launched into a fall semester field experience at JeffCo's Green Mountain High School, where she observed and assisted with everything from grading papers to developing lesson plans.

This type of early, real-world exposure to the teaching profession is a critical component to the teacher prep program. The NSF grant is funding 10 paid internships annually for first- and second-year students, giving them an opportunity to experience the teaching field and see if it's a good fit. With proper planning, a student can complete Mines degree and teacher-licensure requirements within five years.

JeffCo Public Schools jumped at the chance to partner with Mines and UNC by offering students field experiences in its schools. "We want to give them authentic STEM teaching experiences," said Matthew Flores, JeffCo's executive director of curriculum and instruction, noting that they'd like to expand the program to include even more schools and student teaching as well.

"There's an art and science of teaching, as there is an art and science of engineering," Flores added. "The blending of those two takes a unique skill set."

To develop that skill set, the teacher prep program includes 21 credits of education coursework offered by UNC online or on the Mines campus, in addition to Mines

degree coursework. Field experience is required for licensure, so master teachers in residence at Mines are helping to train, place and observe teacher candidates in the classroom. After graduation, candidates do a semester of supervised student teaching before taking a licensure exam.

The NSF is providing scholarships for Mines teacher prep students through its Noyce Scholarship Program, and to keep them in the profession, the scholars also will receive mentoring and professional development throughout their first year of teaching. In exchange for each year of scholarship support, graduates have to teach two years in a high-needs district or their scholarship reverts to a loan.

"Two premier institutions are combining the best minds and best programs to produce incredible teachers," said UNC Associate Professor Christy Moroye. "One of the exciting opportunities we have with this program is to help all of our STEM teachers to become culturally competent so they can help diverse students see themselves as scientists and engage in those professions."

That pipeline idea again: Great scientist-teachers, inspiring a diverse population of young students to become great scientists and teachers.

"Mines wants to make sure we're recruiting from within [K-12] classrooms the next generation of students coming into Mines," noted H. Vincent Kuo, a Mines teaching professor of physics. "What better way to do that than to place our students in those classrooms?"

The partnership between a top-tier engineering school and premier teaching college is unique, and a confluence of factors made the cross-institutional collaboration possible: Two non-competing universities with focused roles and missions; a recognized public need that fit the missions of both schools; supportive administrators; and passionate, collaborative faculty members willing to do the heavy lifting.

"There's always been a latent high level of interest in [Mines] students entering teaching," said Gus Greivel, a Mines professor of applied mathematics and statistics who's been collecting data on teaching interest since 2006.

We always hear about the perception of teaching as a second choice. We need to put our best and brightest in the classrooms... many of the nation's best and brightest can be found at Mines.

—Wendy Adams, director of science education programs and associate professor of physics, natural and health sciences at the University of Northern Colorado

Data show that 20 percent of Mines students surveyed in 2014 would either "definitely plan to enter a teacher prep program" or were "likely to enroll."

But the complications of creating a cross-institutional program of this type were myriad. How would UNC offer coursework to Mines students? How would students register for classes, and how would they pay for them? What about financial aid?

"We were lucky. We have two groups of faculty and administrators on two campuses that saw this as a collaboration, not a competition," said UNC Associate Professor Rob Reinsvold. "The old model would have been, we go out and talk to the Mines students and try to recruit them."

The framework for a partnership was already roughed out when the two schools received a two-year NSF capacity building grant in 2014, and the teacher prep program was ready to enroll a year ahead of schedule. Thirteen students began taking classes in fall 2015, including a PhD candidate who'd just defended her dissertation. By spring 2016, 20 students were enrolled in the program; the ultimate goal is to enroll 80. The program's first graduates will begin student teaching in spring 2017 and will be ready for the classroom that fall.

Meanwhile, faculty members are conducting ongoing research into which recruiting and professional development practices are most successful to recruit and retain STEM teachers, and they're examining perceptions of the teaching profession.

"Institutions like Mines have a responsibility to inform the development of STEM education and STEM career pathways all the way along, from kindergarten on," Greivel said. "We have a vested interest in being part of that conversation and solution."

"In a school surrounded by engineers, telling people you want to be a teacher can be intimidating," said Casner, who will graduate and complete her student teaching next year. "But there's a community of people with the same passion. It makes you proud to be where you're called to be."

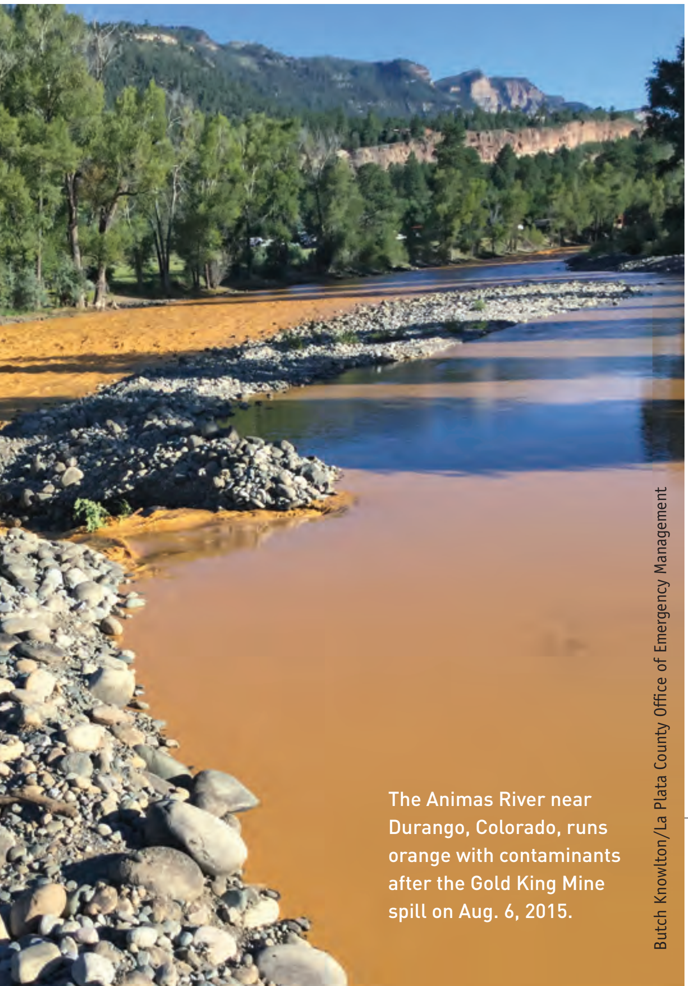
Mending old mines

Mines researchers suggest bioreactors and water-diversion tactics could efficiently help with runoff from abandoned mines

Industry and government agencies are grappling with what to do about the estimated half-million abandoned mines across the U.S. As Colorado looks more closely at how to address hundreds of legacy mines fouling thousands of miles of the state's streams, Mines—with its multidisciplinary expertise and collaborative relationship with industry and government—is poised to play a key role.

Last August the world watched as three million gallons of acid mine drainage poured out of the inactive, 120-year-old Gold King Mine located near Silverton, Colorado, and coursed downstream into the Animas River. Water treatment plants shut off their taps, and alarming photos featuring a river filled with mustard-colored sludge became headline news. Within four days the surface water had cleared and, according to EPA measurements, returned to pre-spill levels of toxic metals.

"This was a wake-up call," said Linda Figueroa, professor of civil and environmental engineering who studies mine remediation techniques. "It lit a fire under the abandoned mine lands community, reminded the public that this is an issue and prompted people to put it back on the front burner."



The Animas River near Durango, Colorado, runs orange with contaminants after the Gold King Mine spill on Aug. 6, 2015.

Butch Knowlton/La Plata County Office of Emergency Management

Mines student Dalton Ellis participates in a field session that assessed the impact of the abandoned Gold Dirt Mine on North Empire Creek, Colorado.

Deirdre O. Keating

Installing multimillion-dollar water treatment plants at all mines is impossible. Alternative technologies are critically needed, and that's where Mines comes in.

London Mine in Park County, Colorado, before and after reclamation efforts, made possible with Freeport-McMoRan funds.

Colorado Division of Reclamation Mining and Safety

As a neutral party and honest broker, Mines hopes to facilitate a stakeholder-wide conversation that can lead to sound and equitable decision making.

"What do we know, and what do we not know? What new technologies need to be developed?" asked Priscilla Nelson, head of the Department of Mining Engineering, who plans to host a summit on the subject in 2016. "Our primary objective is to convene a dialog including all stakeholders (e.g., owners, community leaders, NGOs, consultants, academics and the mining industry). The summit will aim to establish reasonable expectations for mine remediation and closure—both of which are critical for the social license to operate," said Nelson.

The university has a long history of supporting research that has advanced the way mines are operated and reclaimed. And with a growing focus on the environmental and humanitarian aspects of mining, Mines hopes to cultivate a new generation of miners who see themselves as "stewards of the earth's resources," Nelson said.

In the early 1980s, state surveys pegged the number of legacy "hazardous mine features"—such as mine shafts and openings—at 23,000 across Colorado alone.

While many of these mines have been safeguarded, many others still cause issues with stream water quality. In some areas, that degradation results from stormwater flowing through waste piles and tailings, but in many cases, contaminated water flows directly from underground mine tunnels. Efforts by the state such as water treatment facilities and storage ponds have helped address some issues, but much drainage still reaches state waterways. However, installing multimillion-dollar water treatment plants at all of them is impossible. Alternative technologies are critically needed, and that's where Mines comes in.

Mines researchers have been exploring the idea of putting resident microbes to work to help chew up and detoxify waste at legacy mine sites. Today, pilot microbial bioreactor projects are in place in several locations in Colorado and other states and countries.

Figueroa, who designs and researches bioreactors, cautions that at this point, they wouldn't be a good fit for sites with higher water flow rates (Gold King can discharge hundreds of gallons per minute). For those, an active treatment facility works best. But at sites with lots of land to build a microbial system on and a slow, steady flow of acid-rock drainage, bioreactors could provide a cheaper alternative that requires less maintenance. For high-altitude sites, the function of

Mark Ramirez

Environmental engineering students measure water quality parameters for their field session client, Clear Creek Watershed Foundation.

bioreactors could be ensured by accessing the geothermal and solar energy potential available at many sites in Colorado.

"We could make the money go farther and attack more sites," Figueroa said.

Bioreactors aside, Figueroa envisions other ways Mines could partner with the state and industry to move the dial forward on legacy mine cleanups: Rather than relying on boots-on-the-ground surveys to locate troublesome mines, agencies could work with Mines students and researchers to devise ways to use drones, satellite imaging or remote sensing technologies like LIDAR (Light Detecting and Ranging). Instead of focusing on surface water, stakeholders could collaborate with Mines to research how water flows across the land and into the fractured rock, and what changes occur en route that could impact ecosystems, agriculture and groundwater resources. With that knowledge, they could devise better cleanup strategies.

"So far, most of the emphasis is on surface water. At that point, you can't do anything but treat what's coming out," Figueroa says. "My first remediation strategy is not to do a treatment process at all, but to divert the water so it doesn't come into contact with the minerals that can make water quality worse."

While much media attention has been paid to the number of abandoned, historic mines that riddle hillsides across the West, one positive development is often overlooked: Industry practices have changed dramatically since those mines were built.

Today, a company wanting to develop a brand new, or greenfield, mine in the United States can expect to spend a decade and tens of millions of dollars navigating the regulatory process. To get their needed government permits, mine operators must thoroughly assess the potential impact they'll have on air and water, design systems for mitigating these impacts, develop a detailed closure plan (including land revegetation) and put up millions of dollars of financial assurance that they will be able to pay for that plan when the time comes.

Heightened attention to sustainability, combined with tougher regulations, means that the footprint of the mining industry of the future can be far more gentle than it often has been in the past.

A version of this story appeared in the spring 2016 issue of *Mines magazine*.

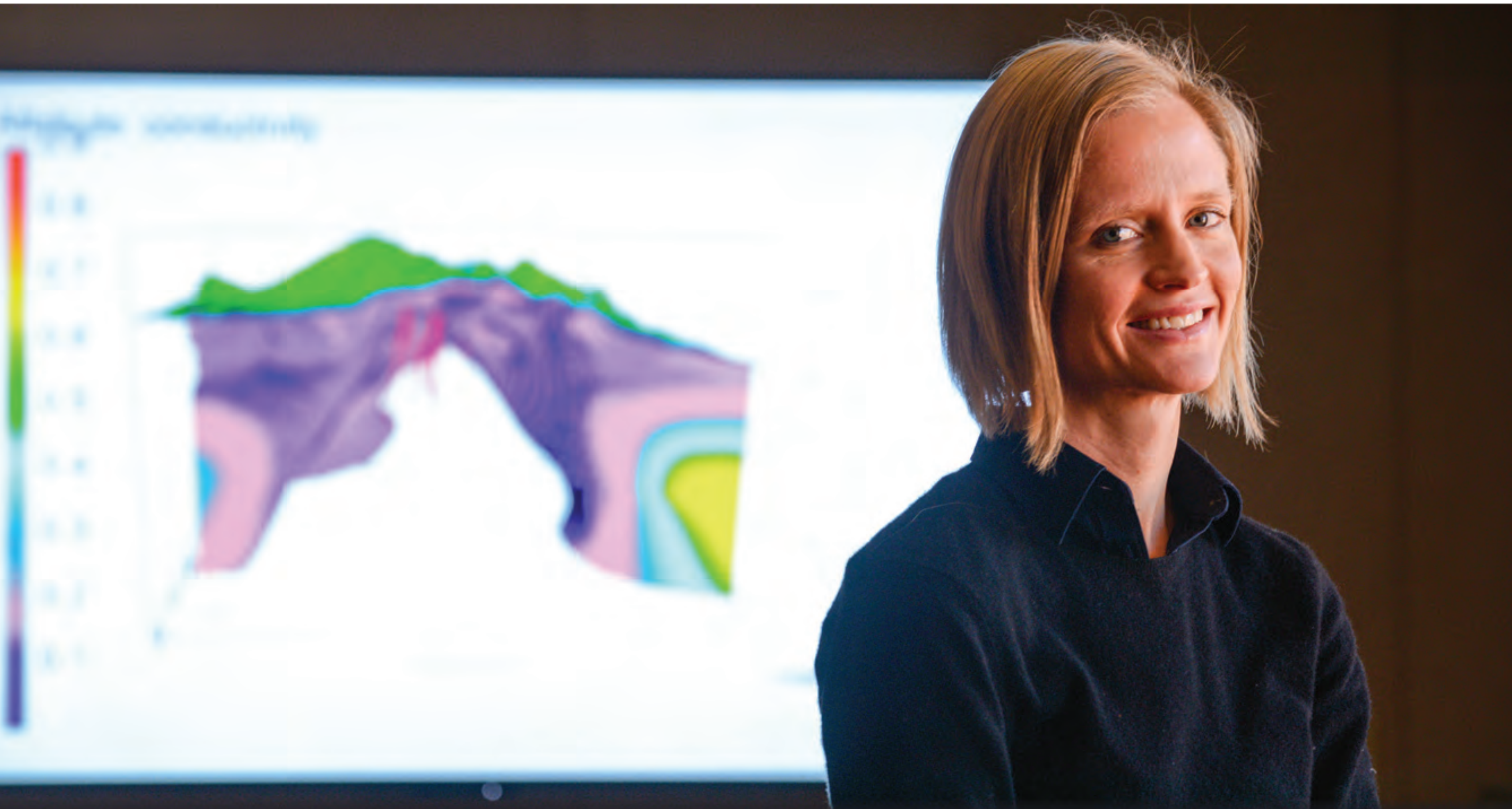
NEW FACULTY

Capitalizing on the university's cross-disciplinary strengths, Mines' internationally renowned faculty members are not only educating the nation's best and brightest future scientists and engineers, but conducting research critical to improving our world.

KYLE LEACH

Assistant Professor, **Department of Physics**

"The biggest question in physics today is how to unify quantum mechanics and the Standard Model (our description of how the universe works on the smallest of scales—atomic nuclei, electrons, other fundamental particles, etc.) with general relativity and cosmology (how the universe works on the largest of scales—effects of gravity, nature of time, etc.) In order to do this, we need to know where, and how, our models fail. My group's research provides stringent tests of the universe on small scales to search for a breakdown in our theoretical understanding of nature that can provide future links to a Grand Unified Theory."



WHITNEY TRAINOR-GUITTON

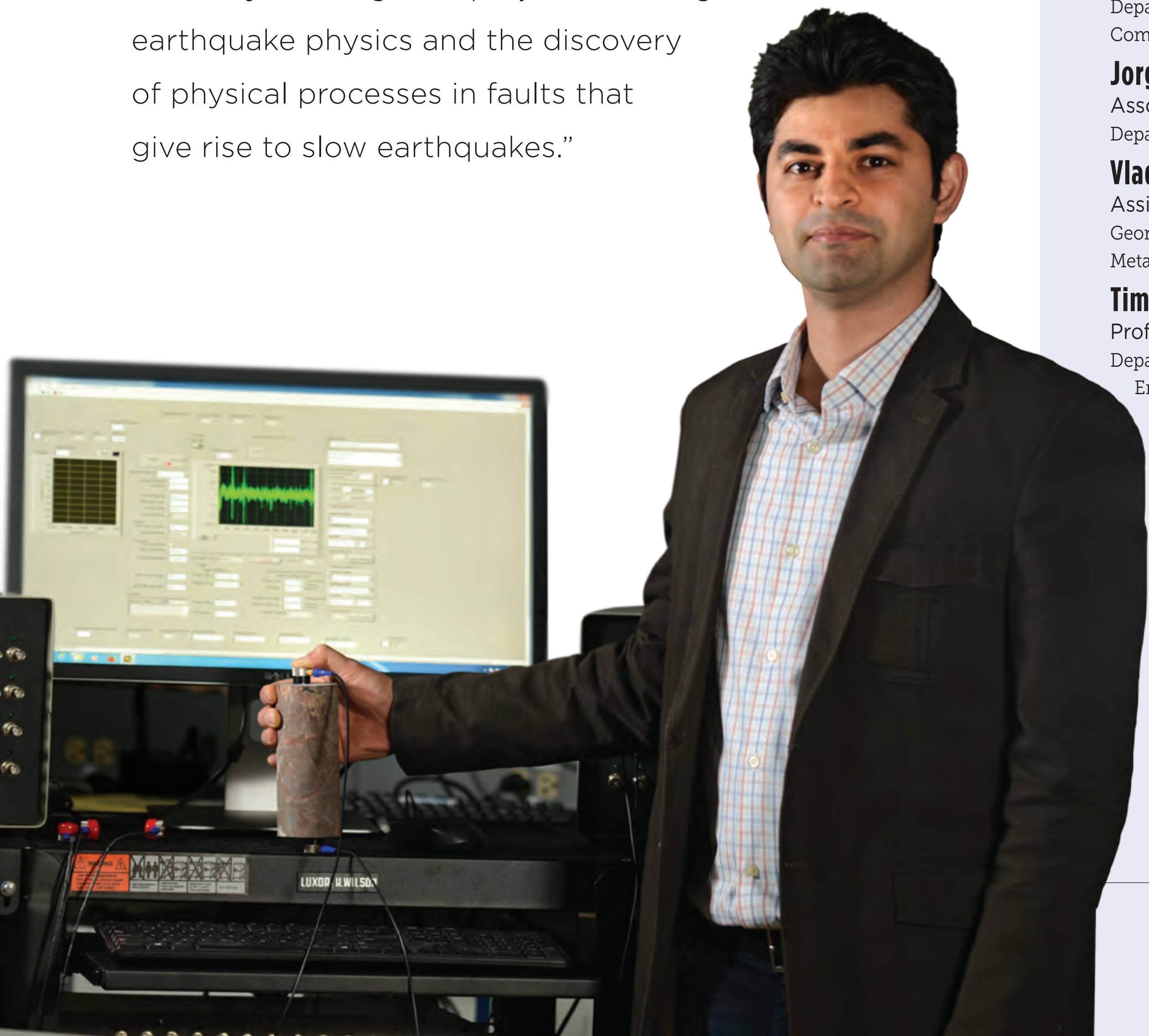
Assistant Professor, **Department of Geophysics**

"My research focuses on methodologies that assess the value of information (VOI) for decisions that affect or are driven by the subsurface—such as, where do we mitigate an aquifer? Or, where do we drill a geothermal exploration well for optimal results? These decisions are difficult because we don't know the properties of the subsurface exhaustively or perfectly. Using this VOI metric, we can determine the best data to use. We are forced to ask how reliable and consequential certain information is to particular decisions, policies or future actions."

REZA HEDAYAT

Assistant Professor, **Department of Civil and Environmental Engineering**

"I use geophysical methods and wave analysis to observe what is happening inside materials with the aim of understanding multiscale physical processes that result in failure, fracturing and slippage in geomaterials. This fundamental research is needed to develop more efficient conventional energy resources, develop emerging technologies such as geothermal energy and carbon sequestration, and deliver sustainable underground infrastructure. My research group is currently working on a project involving earthquake physics and the discovery of physical processes in faults that give rise to slow earthquakes."



2015–16 NEW TENURED/TENURE-TRACK FACULTY

Christopher Bellona
Assistant Professor
Department of Civil and Environmental Engineering

Rosmer Brito
Assistant Professor
Department of Petroleum Engineering

Mark Deinert
Associate Professor
Department of Mechanical Engineering

Eunhye Kim
Assistant Professor
Department of Mining Engineering

Payam Nayeri
Assistant Professor
Department of Electrical Engineering and Computer Science

Jorge Sampaio
Associate Professor
Department of Petroleum Engineering

Vladan Stevanovic
Assistant Professor
George S. Ansell Department of Metallurgical and Materials Engineering

Timothy Strathmann
Professor
Department of Civil and Environmental Engineering

Gabriel Walton
Assistant Professor
Department of Geology and Geological Engineering

Chuan Yue
Assistant Professor
Department of Electrical Engineering and Computer Science

Putting a Dent in the Universe

BY TRACY CAMP, professor of computer science

On March 30, 2016, I was honored to give the 2015-16 Faculty Senate Distinguished Lecture at Mines. This piece briefly summarizes that lecture. In the presentation, I covered my background that led me to a faculty position at Mines in 1998, considered 30 innovations from the previous 30 years to illustrate the impact computing has had on our world, and proposed changes I hope Mines will consider making in the future.

IMPOSTER!

I suffer from imposter syndrome, which means I attribute many of my successes to being "no big deal" and secretly worry that others will discover I'm not as bright as they might think. The fact that I suffer from this syndrome is not surprising, considering I match two of the three attributes for "who's most at risk of the imposter syndrome": I am a first-generation professional, and I work in a job viewed atypical for my gender. Since the third attribute is being a student, I suspect many Mines students (especially our underrepresented and first-generation students) also suffer from this syndrome.

INNOVATIONS!

The 30th anniversary of the PBS "Nightly Business Report" considered 30 innovations that had the greatest impact on business and society. We looked at these innovations and counted the number where computing was involved. At least 22 of the 30 innovations required people with computing expertise, and several attendees counted all 30. In short, computing has put a dent in our universe.

EVERY STUDENT SHOULD LEARN TO CODE

Every student at Mines should learn how to code, as every field is becoming an information field. Coding helps develop critical thinking skills and is a valuable skill. According to the latest U.S. Bureau of Labor Statistics predictions, 77 percent of new jobs in science, technology, engineering and mathematics (STEM) and 58 percent of all jobs in STEM (factoring in replacements) are in computer occupations.

COMPUTING IS SOARING IN K–12

The advanced placement (AP) CS Java Exam is the fastest growing AP exam, and the new AP CS Principles Exam is expected to have even more test takers. President Obama recently pledged $4 billion to fund a "CS for All" program to educate K–12 teachers, as nine out of 10 parents want their child to study computer science but only one in four schools teach computer programming. With several state policy changes at the K–12 level, students entering Mines will soon have more computing skills than ever before.

HOW BEST TO INNOVATE?

Innovation requires inspiration, planning, goals, action, failure, more inspiration, etc. Although complex, one thing is clear—diverse teams are more successful teams. Research studies validate that groups with greater diversity solve complex problems better and faster than homogenous groups.

WE ARE BIASED

We are all biased, and many studies have shown how detrimental unconscious bias is in hiring and promotion. With identical résumés except for the name, Jamal had to send 15 résumés while Greg only had to send only 10 to receive the same number of callbacks. With identical promotion packages except for the name, reservations about Karen's package were expressed four times more often than on Brian's. Sadly, stereotype biases often play into our evaluation of candidates.

Everyone has shortcuts that help us make sense of the world. These shortcuts, however, sometimes make us misinterpret or miss things. Unconscious bias is likely to occur when (1) there exists a lack of critical mass, (2) there exists stress from competing tasks, and (3) there exists a time pressure.

IN SUMMARY

Mines can put an even larger dent in the universe by mitigating imposter syndrome with all students, learning about our biases (and how to avoid them in evaluation), and bringing a more diverse faculty to campus (to innovate better and faster). With the pervasiveness of computing, we should also teach all our students to code and consider creating a flexible CS+X degree program that would get our extended community excited.

Mark Ramirez

Professor Tracy Camp carries the mace during the spring 2016 Colorado School of Mines commencement ceremony. The mace has a rich history as a symbol of authority dating back to the 13th century. In commencement processions, it is carried before the president and dignitaries composing the platform party. It was designed by Professor Emeritus Robert Taylor.

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EARTH • ENERGY • ENVIRONMENT

MINES

Friday Free Pour takes place in Mines' Metallurgical and Materials Department's foundry, giving students across campus the opportunity to experience sand casting.

Photos: Mark Ramirez

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