2008

Research Report

COLLEGE OF ENGINEERING

THE UNIVERSITY OF UTAH

From the Dean

As a dynamic and growing institution, the University of Utah College of Engineering is the focal point for a targeted investment of legislative and university dollars that has significantly moved the needle on engineering graduates and research funding. Beginning in 2001 the college accelerated its growth —in degrees, faculty, research dollars and total funding—at a rate that is roughly twice the national average, attracting the interest of engineering deans nationwide.

The experiment began in 2000 with a vision by then Governor Michael O. Leavitt (now Secretary of Health and Human Services) for a robust regional economy fueled by technology innovation and a healthy local supply of engineering and computer science graduates. Long before the National Academies raised public awareness through the 2005 report, "Rising Above the Gathering Storm," Utah was tackling the issue head on with a one-two funding approach.

First, a multi-year statewide Engineering Initiative led by university, legislative and business leaders pumped millions of dollars into engineering buildings, laboratories, faculty positions and programs, along with public education appropriations to grow the pipeline. As the state's flagship engineering program, the University of Utah seized the opportunity to increase its number of graduates from 368 in 1999 to 607 in 2007. These graduates, along with others from the statewide system, are now supporting one of the strongest regional economies in the nation, boosting Utah's ranking to first in "economic dynamism" according to the Ewing Marion Kauffman Foundation report, "The 2007 State New Economy Index." Utah's powerhouse companies like ATK, IM Flash and L-3 Communications, among others are absorbing annual engineering graduates with an abundance of technical, high-paying jobs. The Utah Technology Council has projected that future job growth for engineers and computer scientists is projected to remain steady at about 25% per year.

Second, the state took another giant step forward in 2006 with the funding of the $400 million Utah Science, Technology and Research (USTAR) Initiative, focused on the University of Utah and Utah State University to the north. Governed by an independent oversight panel, the USTAR investment is being used to attract top research groups in areas of economic interest and existing research strength. The ultimate goal is innovation and discovery leading to technology commercialization, companies and jobs. To date, the University of Utah has succeeded in attracting 13 outstanding faculty members, 10 of whom are associated with the College of Engineering (see below), with active recruitments underway. Construction will soon begin on a $130 million research building to accommodate the growth in faculty and research.

These investments represent a sea change in respect and recognition for the importance of engineering. Visitors comment on the excitement and optimism of our faculty. The legislative investments over the past seven years have been matched by support from the University. In addition, the college completed a $50 million college-focused campaign, adding millions of dollars in capital improvements, scholarships and student support. A new campaign, now in the planning stages, will focus on building the college endowment to sustain recent growth and support future expansion.

The stories in this report are just a sample of the exciting engineering research at the University of Utah. These projects and others represent both the reason for and the result of dedicated investment, and a determination to in fact, “rise above the gathering storm.” The nation might do well to consider the Utah model in its response to meeting future demand for engineering and science professionals.

Richard B. Brown

Dean, College of Engineering
University of Utah

Utah State Capitol in Salt Lake City.

Photo courtesy Utah Office of Tourism (Matt Morgan).

USTAR FACULTY
IN THE COLLEGE OF ENGINEERING

Cameron Charles
Electrical & Computer Engineering

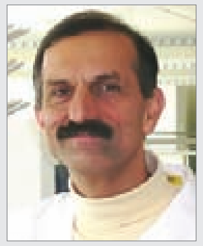
Research interests: radio frequency integrated circuit design, focusing on frequency synthesizers, integrated electronics for phased arrays, and low-power radio transceivers.

P. Thomas Fletcher
School of Computing
SCI Institute

Research interests: shape analysis, differential geometry in computer vision and image analysis, diffusion tensor image processing and analysis, and statistical analysis of multimodal imaging data.

Guido Gerig
School of Computing
SCI Institute

Research interests: using diffusion tensor imaging to characterize neurological disease, characterizing brain shape and growth over time, creating brain atlases, and using DTI to understand the structure of white matter in the brain.



Hamid Ghandehari
Bioengineering
Pharmaceutics & Pharmaceutical Chemistry

Research interests: new polymers for gene therapy, angiogenic inhibitors, oral delivery of chemotherapeutics by polymeric carriers, biocompatibility and cellular trafficking of nanoconstructs, and development of stimuli-sensitive hybrid nanoparticles.

Carlos Mastrangelo
Electrical & Computer Engineering

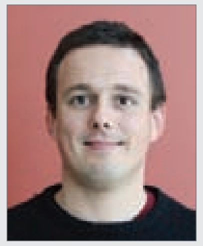
Research interests: micro- and nanosystems for biomedical applications, microsystems for high throughput DNA sequencing, instrumentation of single cells, and microfluidic systems for biological monitoring and drug delivery.

Brian McPherson
Civil & Environmental Engineering
Energy & Geoscience Institute

Research interests: evaluating science and technology of storage of atmospheric carbon in underground geological formations and in surface soil and vegetation.

Marc Porter
Chemical Engineering
Chemistry
Bioengineering

Research interests: nanobiosensors for early disease detection, chromatography, and immunoassay applications, surface acoustic wave devices, surface vibration spectroscopy, and nanoparticle technology.



Tolga Tasdizen
Electrical & Computer Engineering
SCI Institute

Research interests: image processing, computer vision and pattern recognition in high-dimensional feature spaces, computational tools for reconstructing neural circuit diagrams from electron microscopy images.

John White
Bioengineering

Research interests: Understanding how information is processed in the brain through neurophysiology, computational neuroscience, design of real-time instrumentation, and imaging of neuronal activity.

Ling Zang
Materials Science & Engineering

Research interests: manipulation of functional nanostructures and molecular devices; and the investigation of atomic force microscopy, near-field scanning optical microscopy and scanning confocal microscopy.

Building Better Brain Images

"The key elements to conducting medical image analysis and large clinical studies on brain disorders are advanced high-performance computing, development of improved image processing methods and scientific visualization."

Guido Gerig
School of Computing
SCI Institute

With the latest in magnetic resonance imaging (MRI) and dif usion tensor imaging (DTI), researchers at the University of Utah College of Engineering are helping to meet an urgent and growing need for quantitative image analysis techniques and software tools to provide insights into brain disorders.

Guido Gerig, Director for the new Center for Neuroimage Analysis at the University of Utah, is developing tools and techniques that may lead to improved understanding of the disease mechanisms and ultimately help clinicians to better diagnose and treat ailments of the brain.

An expert in image processing, registration, atlas building, segmentation, and shape analysis, Gerig seeks to improve the analysis of medical images of brain tissue—an important step toward understanding and improving the treatment of developmental and degenerative brain diseases and such mental disorders as schizophrenia, autism, fragile X-syndrome (a form of retardation), chronic depression and Parkinson's disease.

"The key elements to conducting medical image analysis and large clinical studies on these disorders are advanced high-performance computing, development of improved image processing methods and scientific visualization," says Gerig, who is also Professor in the School of Computing and a member of the Scientific Computing and Imaging (SCI) Institute at the University of Utah. Gerig was recruited as part of USTAR (or Utah Science Technology and Research initiative)—a legislative initiative to strengthen technological research and stimulate economic development in the state of Utah.

Gerig's brain imaging team includes Marcel Prastawa, Research Assistant Professor in the School of Computing and SCI; Sylvain Gouttard, Research Associate at SCI; and Casey Goodlett, Graduate Research Assistant at SCI. The team works with researchers from the University of Utah's Brain Institute—Associate Professor Ross Whitaker and Assistant Professor Tom Fletcher, also both in the School of Computing and SCI—and UCAIR, the Utah Center for Advanced Imaging Research, on state-of-the-art imaging tools to make optimal use of the rapidly improving imaging technology.

"I am enthusiastic that my expertise in collaborative neuroimage analysis research coupled with the excellence of the SCI Institute and the excitement of the University to form a strong Brain Institute will help us to make a dif erence and to have a strong impact," says Gerig.

THE PROCESS OF IMAGING AND ANALYZING

The Center for Neuroimage Analysis works with radiologists and imaging researchers to determine optimal techniques for performing computed tomography (CT) and MRI scans for research studies.

"The scanning process often involves trade-of s between scan speed and data quality," says Gerig. "Longer scans can achieve higher resolution; however, scan time is limited due to patient comfort, cost of machine use and movement of the patient."

Once data is obtained from the scanner, the image must be processed to extract relevant information, such as brain volume, blood f ow, size and shape of brain structures, and thickness of the cortex. But it is up to innovators like Gerig to make better sense of the data, and create software systems and other tools to extract more useful information.

Gerig's group also focuses on the automatic detection and precise measurement of abnormal brain tissue, including lesions associated with multiple sclerosis or lupus. These quantitative assessments of brain diseases over time will improve diagnostic techniques, as well as monitor the success of new treatments.

FOCUS ON AUTISM

One main area of study for Gerig and his team is developing new tools to understand how the brain changes in young children with autism. In a study funded by the National Institutes of Health with the Autism Center of Excellence, Gerig uses MRI and DTI brain scans to create detailed models of healthy development and of infants at risk for autism.

Gerig's neuroimaging studies have revealed enlargement of brain structures in children with autism as early as two years of age.

Non-invasive MRI/DTI studies of infants at high risk for autism studied at six, 12 and 24 months will provide important information about early stages of this brain disorder. These discoveries may lead clinicians to recommend starting therapy in children as young as one year, which may significantly improve outcomes.

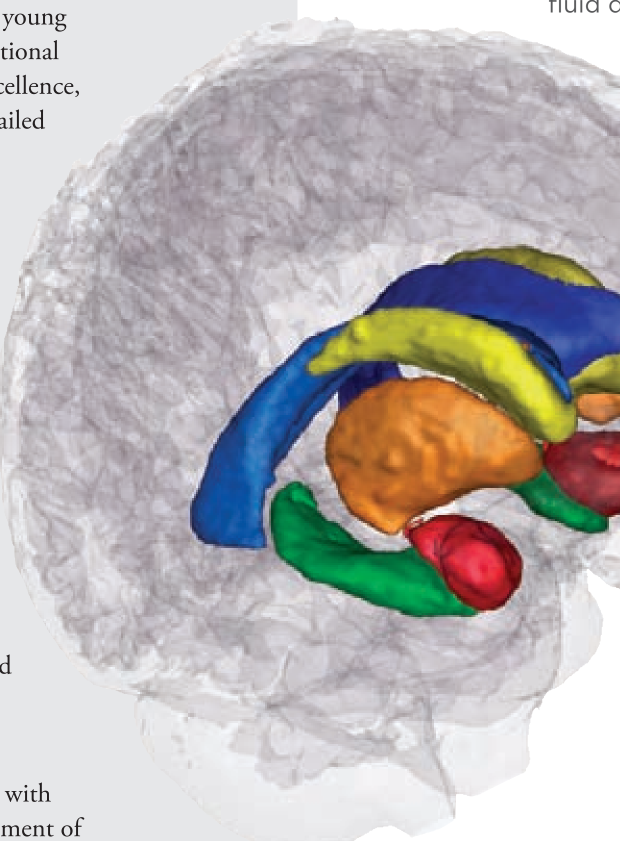
The Center for Neuroimage Analysis works closely with autism expert Dr. Janet Lainhart at the U's Department of Psychiatry using neuroimaging to study the association of cognitive features and brain connectivity. Their goal is to more fully understand the cognitive deficits associated with alterations in fiber tracts connecting major brain regions.

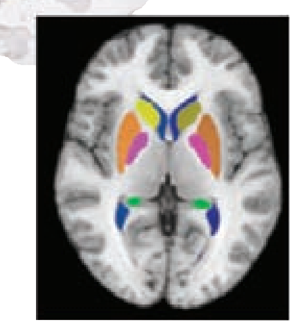
"A very strong motivation for my group is that our research may ultimately help families and improve the quality of life for children at risk for developmental and degenerative brain diseases," says Gerig.

A Leader in Computing & Imaging Research

The Scientific Computing and Imaging *(SCI)* Institute, under the leadership of Professor Chris Johnson, has established itself as an internationally recognized leader in visualization, scientific computing and image analysis research, that is home to more than 100 faculty, students and staff. Faculty are drawn primarily from the College of Engineering's School of Computing and Department of Bioengineering.

The SCI Institute's overarching research objective is to create new scientific computing techniques, tools and systems that enable solutions to problems affecting various aspects of human life. Researchers solve challenging computational and imaging problems in biomedicine, geophysics, combustion, molecular dynamics, fluid dynamics and atmospheric dispersion.





This image shows automatic detection of brain structures from a patient MRI using software developed by the Utah Center for Neuroimage Analysis led by Guido Gerig.

Research in autism, schizophrenia and Alzheimer's disease particularly looks at the volume and shape of the hippocampus (green), amygdala (red) and caudate (yellow).

The Key to Provenance

Building New Technologies to Manage Complex Data

Computers help accelerate scientific advances, leading to an information explosion in many different fields. As ever-increasing amounts of data are generated, future scientific advances depend on investigators' abilities to assemble complex computational processes to analyze these data and generate insightful visualizations.

Today, ad-hoc approaches to data exploration (for example, Perl scripts) are widely used in the scientific community, but they have serious limitations. In particular, scientists and engineers expend substantial effort managing data (scripts that encode computational tasks, raw data, data products and notes) and recording provenance (a documented history of computerized data) information, so they can track who created a data product and when, what process was used to create it, and so on. Not only is the process time-consuming but also prone to error.

"Without provenance, it's difficult to reproduce and share results, solve problems collaboratively, or validate results with different input data," says Juliana Freire, Associate Professor in the School of Computing at the University of Utah College of Engineering.

Recently, workflows and workflow-based systems have emerged as an alternative to the ad-hoc approaches to data exploration. They can capture complex analysis processes at various levels of detail for reproducibility, results publication and sharing. However, these systems have been traditionally used to automate repetitive tasks and are not suitable for applications that are exploratory in nature, where change is the norm.

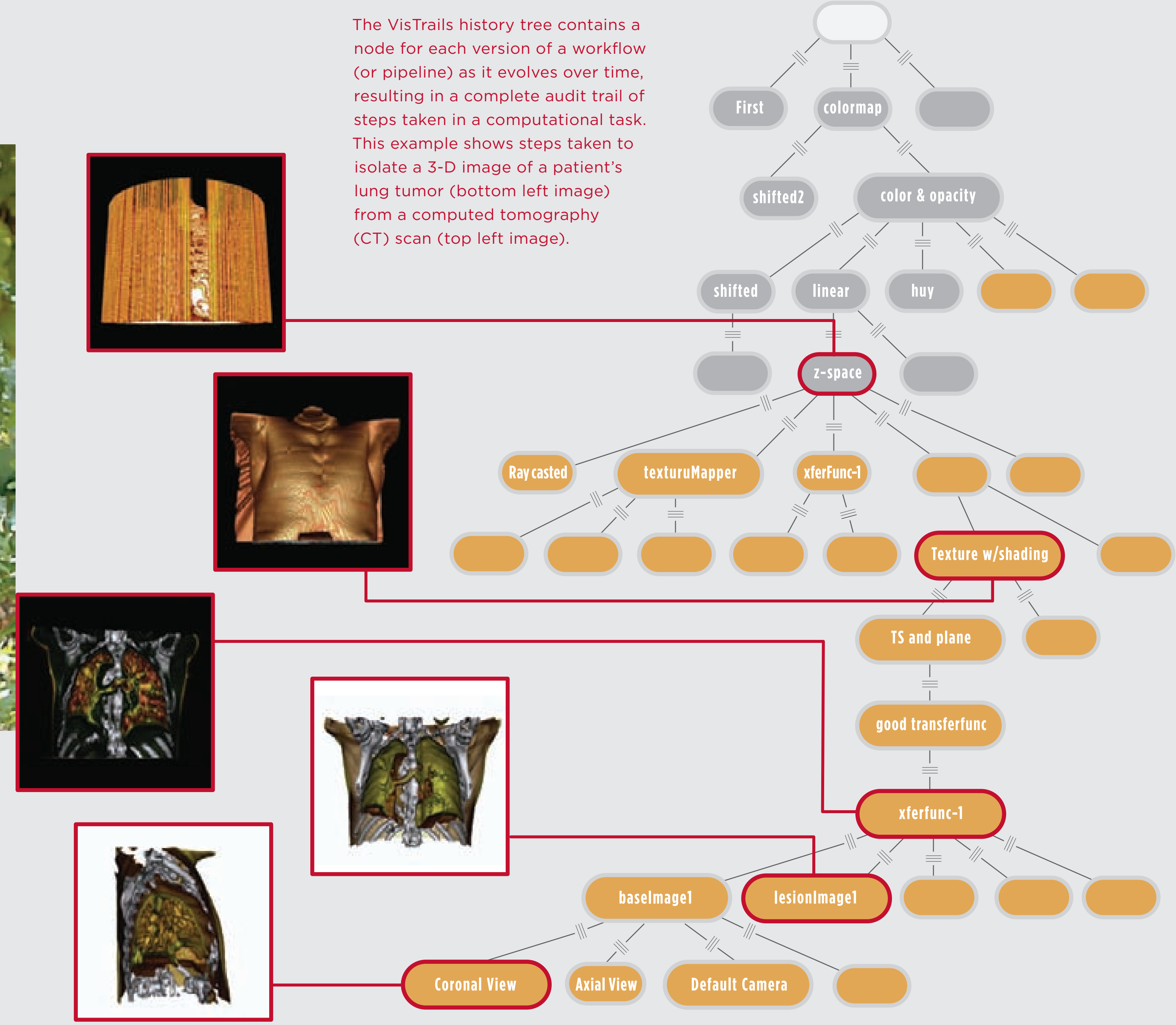
DEVELOPING VISTRAILS

The lack of adequate information and provenance management in workflow and workflow-based systems motivated Freire and Claudio Silva to develop VisTrails (*www.vistrails.org*), an open-source provenance management system designed to support visualization, data mining and integration. VisTrails tracks the steps taken to produce digital products such as spreadsheets, computer animation and medical imaging. Freire is co-principal investigator of the project with Silva, also Associate Professor in the School of Computing and a faculty member in the Scientific Computing and Imaging (SCI) Institute.

> "VisTrails introduces a set of critical new technologies that support and streamline exploratory computational tasks," says Freire.

"By capturing provenance both of data products and the workflows that derive them, VisTrails not only reproduces results but allows users to easily navigate workflows and parameter settings. Users can undo changes, compare different workflows and be reminded of the actions that led to a particular result."

An important goal of the VisTrails project is to create tools for scientists without programming expertise. As part of its provenance infrastructure, the VisTrails system provides usable interfaces that support collaboration and knowledge re-use. These include an



The VisTrails history tree contains a node for each version of a workflow (or pipeline) as it evolves over time, resulting in a complete audit trail of steps taken in a computational task. This example shows steps taken to isolate a 3-D image of a patient's lung tumor (bottom left image) from a computed tomography (CT) scan (top left image).

interface for querying workflows and provenance by example, a mechanism for refining workflows by analogy, and a recommendation system that aids users in the design of workflows.

NSF CAREER AWARD

As part of a broader look at provenance management of computational tasks, Freire was recently awarded a five-year $500,000 National Science Foundation (NSF) CAREER Award. Her goal is to produce new algorithms and techniques to help scientists manage large quantities of scientific data and workflows, and efficiently explore useful knowledge embedded in their provenance.

The CAREER Award is one of the NSF's highest honors for young faculty members. Freire's award was one of four CAREER Awards received this year by College of Engineering faculty.

WOMEN IN COMPUTER SCIENCE

An additional aim of Freire's NSF CAREER Award is to design an introductory computer science course and workbook on problem solving, which she hopes will attract more women to the field of computer science.

Low enrollments of students, particularly women, in computer science have been attributed in part to the misconception that computer science involves only programming—a notion reinforced in many undergradate courses.

"The provenance infrastructure and tools to be developed in my NSF career research will serve as a platform where students can learn computer science and solve computational problems before getting into programming," says Freire.

Clear the Air

Confronting Global Warming with Carbon Capture and Storage

Burying and storing carbon dioxide in the earth may not only fight global warming but also assist in oil recovery. Engineers at the University of Utah College of Engineering are conducting studies to inject CO_2 created by coal power plants thousands of feet underground to store it safely away from the atmosphere and to push out hard-to-reach oil.

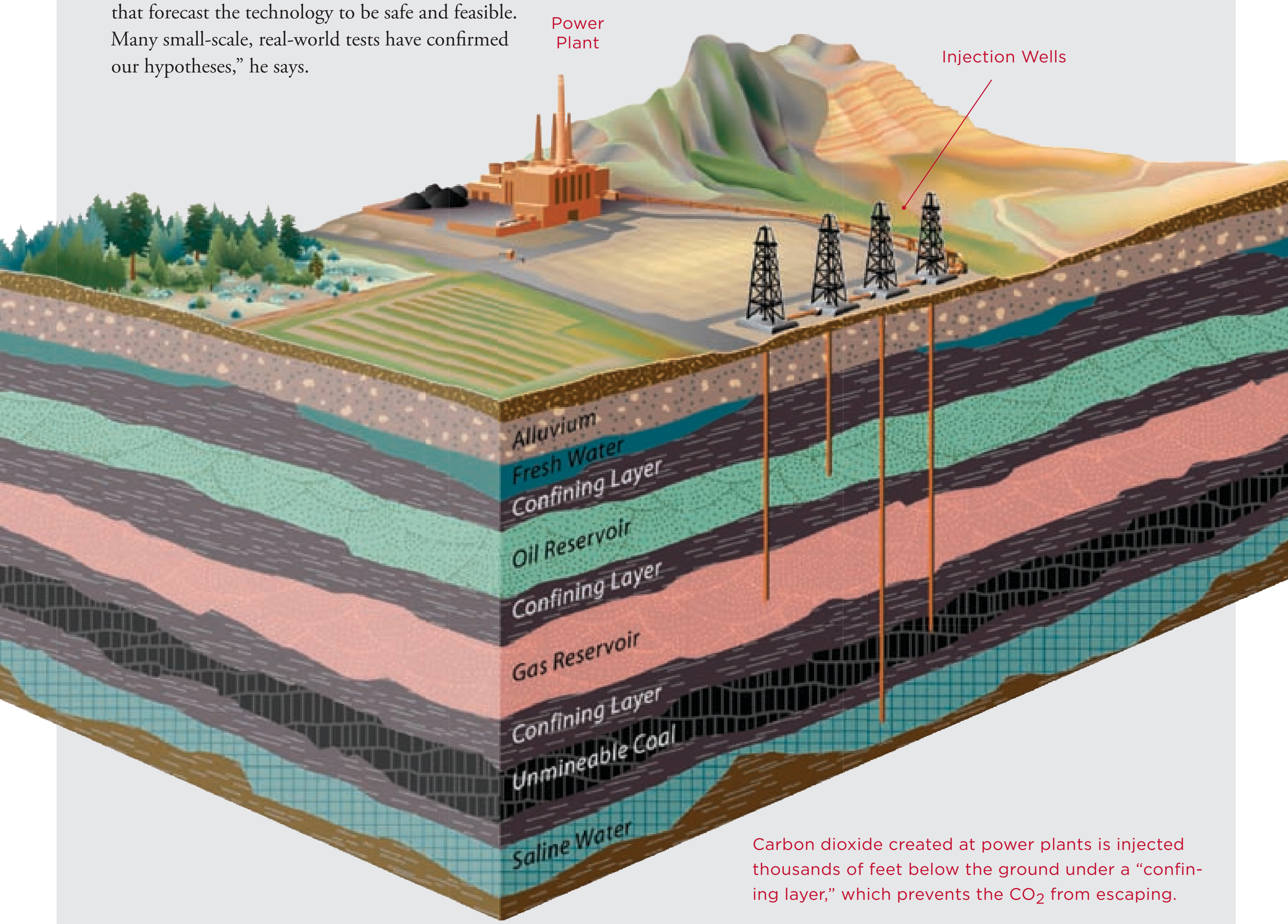
Called carbon capture and storage, the process takes CO_2 emissions that would otherwise go into the atmosphere and stores them deep underground, just as nature has stored natural gas below Utah sandstone for millennia.

"Carbon dioxide has been injected into the subsurface for enhanced oil recovery for several decades," says project leader Brian McPherson, Professor in the Department of Civil and Environmental Engineering and a member of the Energy and Geoscience Institute at the University of Utah College of Engineering.

"We have developed sophisticated computer models that forecast the technology to be safe and feasible. Many small-scale, real-world tests have confirmed our hypotheses," he says.

In recovering oil, the carbon dioxide pushes oil out of the ground that otherwise could not be pumped out. The same CO_2 that assists oil recovery is trapped underground where it can't enter into the air. One Department of Energy analysis estimates that Utah could recover 2.8 billion barrels of oil using CO_2—enough oil to supply gasoline to the state's drivers at current levels for more than 80 years.

McPherson is Creator and Project Director of the Southwest Regional Partnership for Carbon Sequestration, one of seven regional partnerships funded with a $67 million grant from the U.S. Department of Energy to evaluate the science and technology of atmospheric carbon storage in underground geological formations and in surface soil and vegetation. McPherson is a new faculty member hired through USTAR (or Utah Science Technology and Research initiative), a long-term, state-funded investment in world-class innovation teams and research facilities at the University of Utah.



Carbon dioxide created at power plants is injected thousands of feet below the ground under a "confining layer," which prevents the CO_2 from escaping.

CO2: A GLOBAL PROBLEM

Many people attribute excessive carbon dioxide in the atmosphere to global warming. "The amount of CO_2 is much higher than we've ever before measured," McPherson says.

"Although we don't have a 'silver bullet' to solve the global carbon-emissions problem, I think it's clear that we need a portfolio of options with short-term and long-term solutions," he says. "Carbon capture and storage is one of our important resources for the relative short-term."

Efficiency measures can be implemented immediately, he says. Wind, solar and geothermal renewables can be employed now, but it will take many years to replace coal-fired power plants with new forms of energy.

TESTING CARBON CAPTURE AND STORAGE

McPherson and his colleagues are currently field-testing carbon dioxide injection for storage concepts and potential impacts on the subsurface environment. They are conducting several large-scale tests near coal and natural gas power plants. Existing pipelines could be used to transport CO_2 to geologic storage sites. McPherson says that significant storage infrastructure could be in place as early as 2020.

By the beginning of 2009, McPherson's group will begin the largest single-injection storage project in the United States. At a testing site near Price, Utah, they will inject one million tons of liquid CO_2 per year and use sophisticated monitoring to determine the safety of the technology.

"If our tests show that carbon capture and storage can be fully realized, then this technology will have enormous benefits," says McPherson. "It will give innovators time to develop renewable energy that is cleaner for our environment and that will help us break our dependence on fossil fuels."

> Even the most aggressive projections of renewable energy development show a need to achieve 1990 emission levels before it's too late. Carbon capture and storage is much closer to being ready for 'prime time' than many other carbon-reducing approaches.

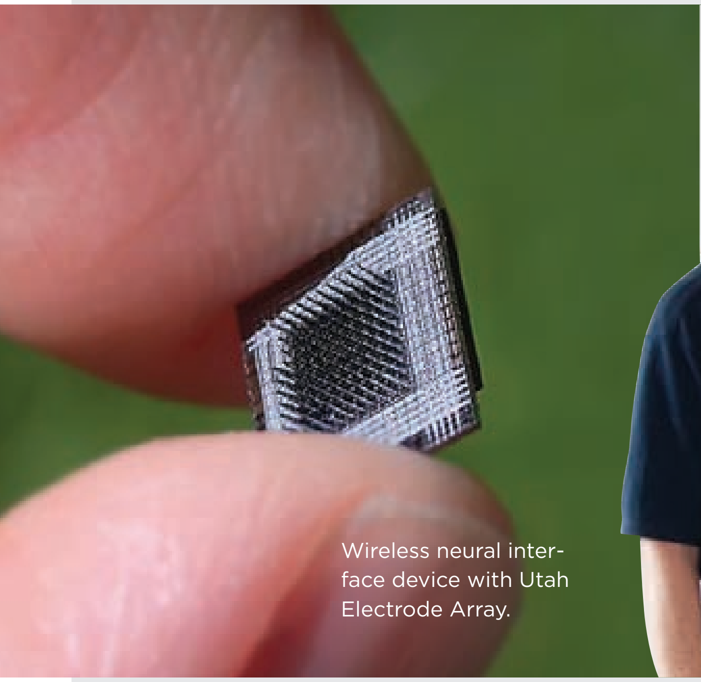
Brian McPherson
Civil & Environmental Engineering
Energy & Geoscience Institute

Energy Excellence at the College of Engineering

The Energy & Geoscience Institute *(EGI)* at the University of Utah College of Engineering has a 25-year record of conducting multidisciplinary projects worldwide in such areas as fossil energy, geothermal research and environmental engineering. Directed by Professor Raymond "Ray" Levey, the Institute undertakes a broad range of projects on all seven continents through cooperative agreements with universities and research institutes, government agencies and laboratories, and national energy companies worldwide.

The Institute for Clean and Secure Energy *(ICSE)* was organized from a long tradition of combustion research at the University of Utah College of Engineering beginning in the 1950s and continuing to today. Directed by Professor Philip Smith, ICSE employs an integrated, multi-disciplinary approach to the study of energy, combustion and high-temperature fuel-utilization processes by combining hands-on experimental work with analytical tools and simulation.

Improving Life and Limb: Transforming the World of Neuroprosthetics



Wireless neural interface device with Utah Electrode Array.

From left to right:

- **Richard Normann, PhD** *Bioengineering*
- **Paul House, MD** *Neurological Surgery*
- **Florian Solzbacher, PhD** *Electrical & Computer Engineering*
- **Shane Guillory, PhD** *Ripple LLC, a SLC neurophysiology instrumentation & neuroprosthetic startup*
- **Bradley Greger, PhD** *Bioengineering*
- **Greg Clark, PhD** *Bioengineering*
- **Reid Harrison, PhD** *Electrical & Computer Engineering*
- **Patrick Tresco, PhD** *Bioengineering*
- **Nicholas Brown, PhD** *Orthopedics*
- **Michael Toepper, PhD** *Fraunhofer Institute for Reliability & Microintegration, Technical University of Berlin*
- **Douglas Hutchinson, MD** *Orthopedics*

Imagine if engineers could create an artificial arm that not only looks real, but also feels real and moves naturally in response to a wearer's thoughts. It may sound like science fiction, but in fact researchers at the University of Utah College of Engineering are helping to develop such a prosthesis for soldiers and eventually for others whose arms were amputated.

The device would allow "you to feel both the outside world and your own movements" and would be "as strong and graceful as an intact, biological limb," says Greg Clark, Associate Professor of Bioengineering and the University of Utah's principal investigator on the project.

> "Our researchers, teaming with others around the world, are setting out to achieve this," says Clark. "People's arms and hands are not only tools, but also an important means by which they explore the world and interact with others. We hope to restore that capability."

Determined to help wounded soldiers, the Department of Defense is sponsoring the Revolutionizing Prosthetics 2009 project through DARPA, or Defense Advanced Research Projects Agency. The University of Utah's part of the project—worth up to $10.3 million over four years—is subcontracted from Johns Hopkins University Applied Physics Laboratory, which is leading the project overall.

"Our focus is on helping people who have been injured, so they can do such important tasks as brushing their teeth, feeding themselves, and picking their kids up and feeling safe about doing that," says Bradley Greger, Associate Professor of Bioengineering on the University of Utah team.

A BETTER ARTIFICIAL ARM

A multi-disciplinary team of engineers and other researchers are focusing on developing and testing two types of wireless neural interfaces invented at the University of Utah: a peripheral nerve interface and a central nervous system interface that would be used with the artificial arm.

Both interface devices use a modified Utah Electrode Array, a pill-sized device containing 100 tiny electrodes that was invented by Distinguished Professor of Bioengineering Richard Normann.

The two interfaces would work in parallel and provide redundancy in this multi-level approach. The peripheral nerve interface would be implanted in each of the three nerves of the residual limb and relay nerve impulses to a small computer worn on a belt and then to the artificial arm. That would allow a person to move the artificial arm like a real one. Sensors in the artificial arm would send signals to the computer and on to the interface device, which would relay the signals to nerves in the remainder of the amputated arm and then to the central nervous system interface implanted in the brain, allowing the person using it to sense the arm's motion and location, and to feel objects with the mechanical hand and fingers.

Researchers at other institutions, meanwhile, are developing the new prosthetic arm itself. Existing prosthetic arms have limited, single movements, such as bending the elbow and wrist and opening and closing the hand; however, the new arm will be capable of about 20 dif erent movements, including moving fingers independently.

"The new arm will take the signals that go to all the dif erent arm muscles at once, and all the person has to do is think about natural movement and the arm will respond in a natural way," says Clark. "We're basically listening in on what the nervous system would be telling the natural arm, and translating that into signals that will move the artificial arm in the same way."

TWO PHASES OF DEVELOPMENT

During the first two-year phase of development, University of Utah researchers focused on developing and refining the interface and computer technologies. Now in phase two, researchers are further refining and testing the technologies.

> "Once we've conducted all of the testing and made the necessary improvements, we can go to the FDA for approval," says Greger. "We're developing devices that must last for many years, so we build in multiple levels of interface and redundancy as safeguards. Failure of the devices is not an option."

As principal investigator for the Utah part of the prosthetic arm program, Clark oversees the project. He and Greger will also participate in preclinical and human studies of the interface device with Douglas Hutchinson, Associate Professor of Orthopedics, who will perform the peripheral nerve implantations, and Paul House, Assistant Professor of Neurosurgery, who will perform the central nervous system interface implantations for clinical trials once the devices are FDA-approved.

"The Utah neural interface technology is the enabling technology allowing for a bidirectional direct interface with the nervous system," says Florian Solzbacher, Associate Professor of Electrical and Computer Engineering, who is developing and fabricating the array's components and encapsulating the interface devices to make them durable and safe for implantation.

Other University of Utah co-principal investigators are Normann, who is enhancing the electrode array's capabilities for operating the artificial arm; Reid Harrison, Associate Professor of Electrical and Computer Engineering, who is developing the wireless chip technology that interfaces with the array; Patrick Tresco, Professor of Bioengineering and Associate Dean for Research at the College of Engineering, who is performing the biocompatibility testing; and Shane Guillory, a former University of Utah bioengineering graduate student and Founder of Ripple, LLC, who is developing the computer that relays signals between the arm and the brain.

NEXT STEPS

Once rigorous testing of the interface devices is completed in a minimum of two years, engineers hope that the prosthesis could begin early clinical trials in which a few select individuals could be fitted with the device for testing in humans. That the University of Utah was chosen for the project "is a testament to the high quality of research that has been conducted here, and to the expertise of the many investigators on the research team," Clark says.

"Utah is one of the few places that is up to the challenge of developing the neural interface technology," says Greger. "The Utah Electrode Array developed here is a big part of that. It has historically attracted a team that has the broad set of very advanced skills needed to make this work. This is what is unique about Utah."

Fuel Cells

A Cleaner, More Efficient Way to Produce Energy

Concerns about rising gas prices and global warming are helping to drive the research and development of new energy technologies. Society as a whole is seeking alternative ways to generate power that are cheaper, and more efficient and environmentally friendly than current modes of energy generation.

Such fossil fuels as coal, natural gas, and crude oil, are among the most widely used energy resources in the world. Energy is generated centrally through turbines at coal or natural gas-fired plants, as well as hydropower or nuclear plants. Electricity is then supplied to residential and industrial customers by a distribution network or "grid." Although there are important benefits to centralized power plants, there is substantial cost to constructing and maintaining new infrastructure. Low efficiency in combustion-based turbines contributes to cost and wastes energy. Additionally, in developing countries in particular, the lack of infrastructure is a major impediment to supplying electricity to consumers.

Because fossil fuels have been—and continue to be—an important part of our energy infrastructure, a team of University of Utah engineers is working to develop fuel cell technology to use fossil fuels in a more economical and eco-friendly manner. Moreover, such fuel cells could be used in both developed and undeveloped areas of the world as long as the consumer has access to fuel.

"Fuel cells may be an important part of the solution to our energy problems," says Anil Virkar, Chair of the Department of Materials Science and Engineering at the University of Utah, whose lab oversees the project.

"Eventually if there is widespread adoption of the technology, it's conceivable that we could cut the use of oil in this country alone by 50 percent. Further, I think eventually fuel cells could contribute 10 to 20 percent of the United States' energy needs, which is significant."

HOW FUEL CELLS WORK

Although there are many kinds of fuel cells, one type that Virkar and his team are developing is solid oxide fuel cells (SOFC)—also known as ceramic fuel cells because their main components are made of ceramic—electrochemical devices that operate on a number of carbonaceous fuels that convert chemical energy of oxidation into electricity.

Unlike typical turbine combustion engines that burn fuel and produce pollution, SOFCs convert fuel directly into electrical energy without direct combustion or moving parts. The lack of direct combustion virtually eliminates harmful emissions. Fuel cells also use a lot less fuel than turbine engines to produce the same amount of energy.

All fuel cells consist of three basic parts: a cathode, an anode and an electrolyte. In an SOFC, the cathode processes oxygen molecules from air that accept electrons to form negatively charged oxygen ions. The oxygen ions move through the solid ceramic electrolyte to the fuel side. At the anode, fuel uses oxygen to form water vapor and carbon dioxide and the electrons are released. These electrons are transported through the external circuit as an electrical current, and are returned back to the cathode to complete the loop.

An anode-supported solid oxide fuel cell (SOFC).

> "In a sense, a fuel cell is like a battery, except that both the fuel and oxidant are continually supplied to the anode and cathode," says Virkar.

USES FOR FUEL CELLS

Although the potential for fuel cells is nearly limitless, Virkar is looking at common, but important, everyday applications such as heating homes and supplying auxiliary power to automobiles to operate air conditioning, heat and radio without the engine on.

Virkar is co-founder/founding member of three companies that are actively working on fuel cells: Salt Lake-based companies Ceramatec, and Materials and Systems Research, Inc. (MSRI), and a Colorado-based venture called Versa Power Systems. MSRI is building fuel cell units for residential and portable power. The residential units would produce electricity, hot water and heat.

"The SOFC system would operate on natural gas or other fuels and allow consumers to generate their own electricity on-demand," he says. "At higher power capacity, such units could be installed in hospitals, office buildings, apartment complexes and schools."

Virkar says an important feature of SOFCs is that they can be connected to the power grid of the local utility company. So if a consumer needed additional power, it could be purchased from the utility company. Alternatively, excess electricity produced in the home could be sold to the company. Because SOFC units operate at high temperatures—the same as a residential furnace—they may eventually replace the furnace in a typical household.

While much of the work in Virkar's group is on SOFCs, he has also recently begun work on PEMFCs (proton exchange membrane fuel cells). These low-temperature fuel cells could potentially replace the internal combustion engine in automobiles. The PEMFC uses less fuel, converting gasoline into hydrogen, water vapor and carbon dioxide. The hydrogen separates from the gas mixture and the PEMFC operates on hydrogen.

"Some day soon we may see automobiles operating on a lot less gas with fuel cells instead of the internal combustion engine," says Virkar. "Such cars will be, for all practical purposes, essentially pollution-free."

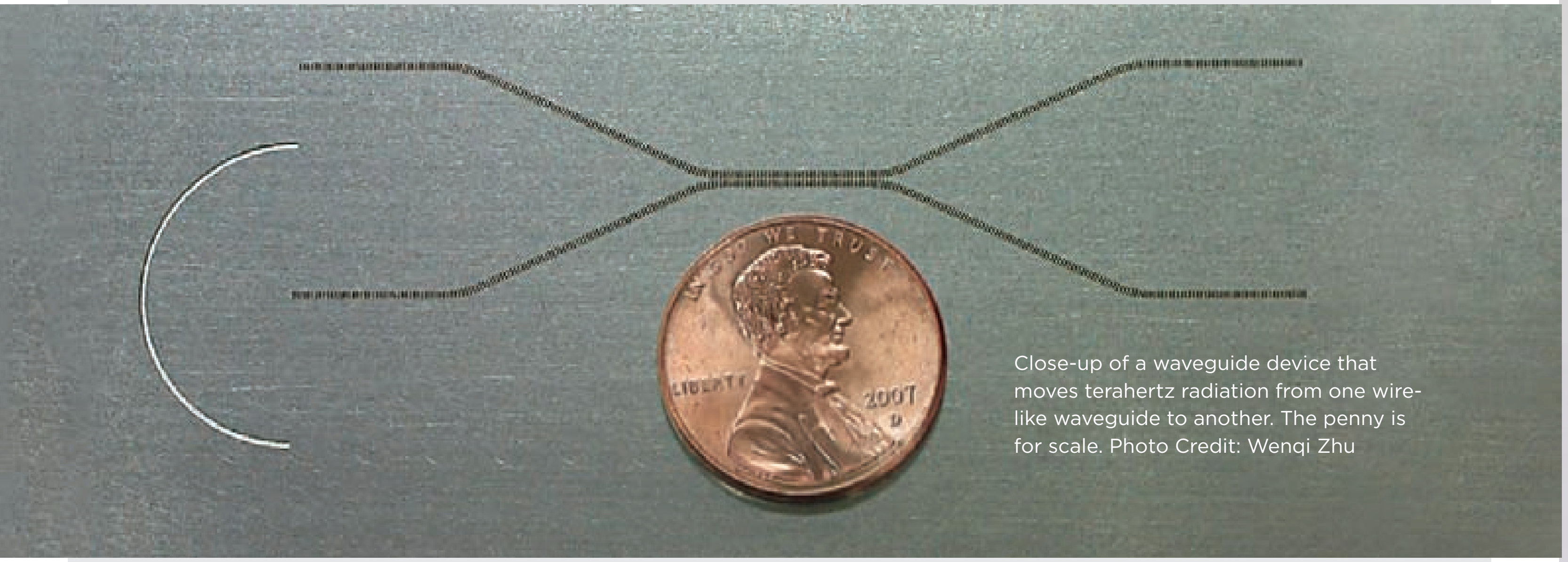
Elected to the National Academy of Engineering

Anil Virkar, Professor and Chair of Materials Science and Engineering, was recently elected to the prestigious National Academy of Engineering. Among the highest professional distinctions accorded an engineer, the academy cited Virkar "for contributions to the development of high-temperature ionic and electronic materials for fuel cells and batteries."

A member of the University of Utah faculty since 1976, Virkar is an internationally respected scholar in ceramics and fuel cell development. Of the academy honor, Virkar said, "I'm very fortunate to have had the opportunity to work at the University for the last three decades and to have had many, many good students."

Terahertz Technology

Harnessing Far-Infrared for Superfast Circuits



Close-up of a waveguide device that moves terahertz radiation from one wire-like waveguide to another. The penny is for scale. Photo Credit: Wenqi Zhu

University of Utah engineers are taking an early step toward developing superfast circuits for communications and computers that run on far-infrared light (also known as terahertz radiation or T-rays) instead of electricity: They made the equivalent of wires that carry and bend this form of light, which is the last unexploited portion of the electromagnetic spectrum.

"We have taken a first step to making circuits that can harness or guide terahertz radiation," says Ajay Nahata, Associate Professor of Electrical and Computer Engineering at the University of Utah. "Eventually—in a minimum of 10 years—this will allow the development of superfast circuits, computers and communications."

Electricity is carried through metal wires. Light used for communications is transmitted long distances through fiberoptic cables. After being split into dif erent colors or "channels" of information, it is conducted on circuit boards using structures called waveguides. But little research has been done on controlling the much higher frequency terahertz signals. In a recently published study, Nahata and two doctoral students in Electrical and Computer Engineering, Wenqi Zhu and Amit Agrawal, designed stainless steel foil sheets with patterns of perforations that successfully served as wire-like waveguides to transmit, bend, split or combine terahertz radiation.

To use terahertz radiation in computing and communications, it must be transmitted from one device to another and processed. "This is where terahertz circuits are important," says Nahata. "The long-term goal is to develop capabilities to create circuits that run faster than modern-day electronic circuits so we can have faster computers and faster data transfer."

CONTROLLING FAR-INFARED LIGHT

The electromagnetic spectrum, which ranges from high to low frequencies (or short to long wavelengths), includes: gamma rays, X-rays, ultraviolet light, visible light (violet, blue, green, yellow, orange and red), infrared light (including radiant heat and terahertz radiation), microwaves, FM radio waves, television, short wave and AM radio.

Fiberoptic phone and data lines now use near-infrared light and some visible light. With so much of the electromagnetic spectrum clogged by existing communications, engineers want to harness terahertz frequencies for communication, much faster computing and even for anti-terrorism scanners and sensors able to detect biological, chemical or other weapons. Nahata says his research is relevant mainly for developing superfast computers.

Nahata and his colleagues found that it was possible to control a signal of terahertz radiation using thin stainless steel foils perforated with rectangular holes arranged in semi-regular patterns. They found a way to manipulate the direction the terahertz radiation moved, such as by bending or splitting it, which is a necessary requirement for making terahertz guided-wave circuits.

TERAHERTZ SPEED

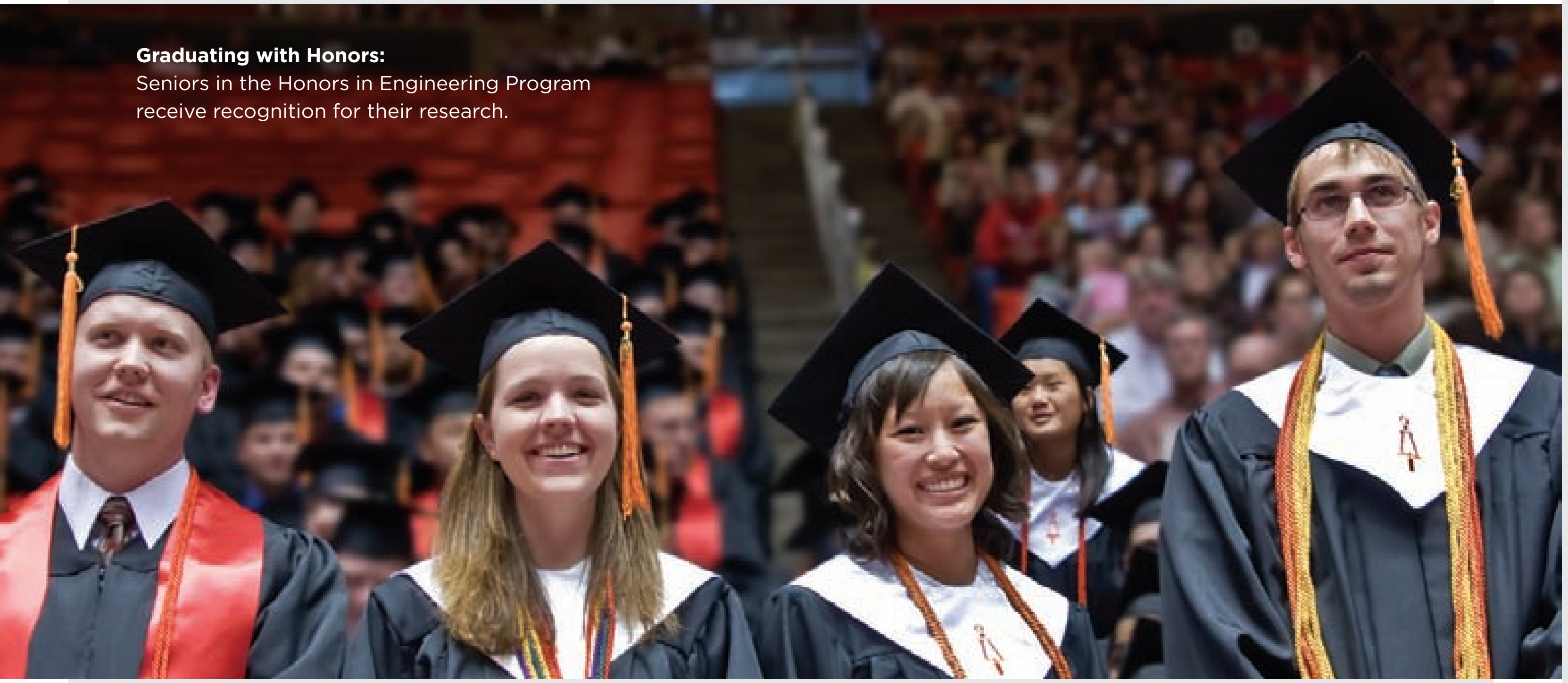
"Electronic circuits today work at gigahertz frequencies—billions of cycles per second. Electronic devices like a computer chip can operate at gigahertz," Nahata says. "What people would like to do is develop capabilities to transport and manipulate data at terahertz frequencies [to make them a thousand times faster than today's gigahertz-speed computers]. It's a speed issue. People want to be able to transfer data at higher speeds. People would like to download a movie in a few seconds."

His team has made the "wires" for terahertz circuits. "Now the issue is how do we make devices such as switches, transistors and modulators at terahertz frequencies?" Nahata says.

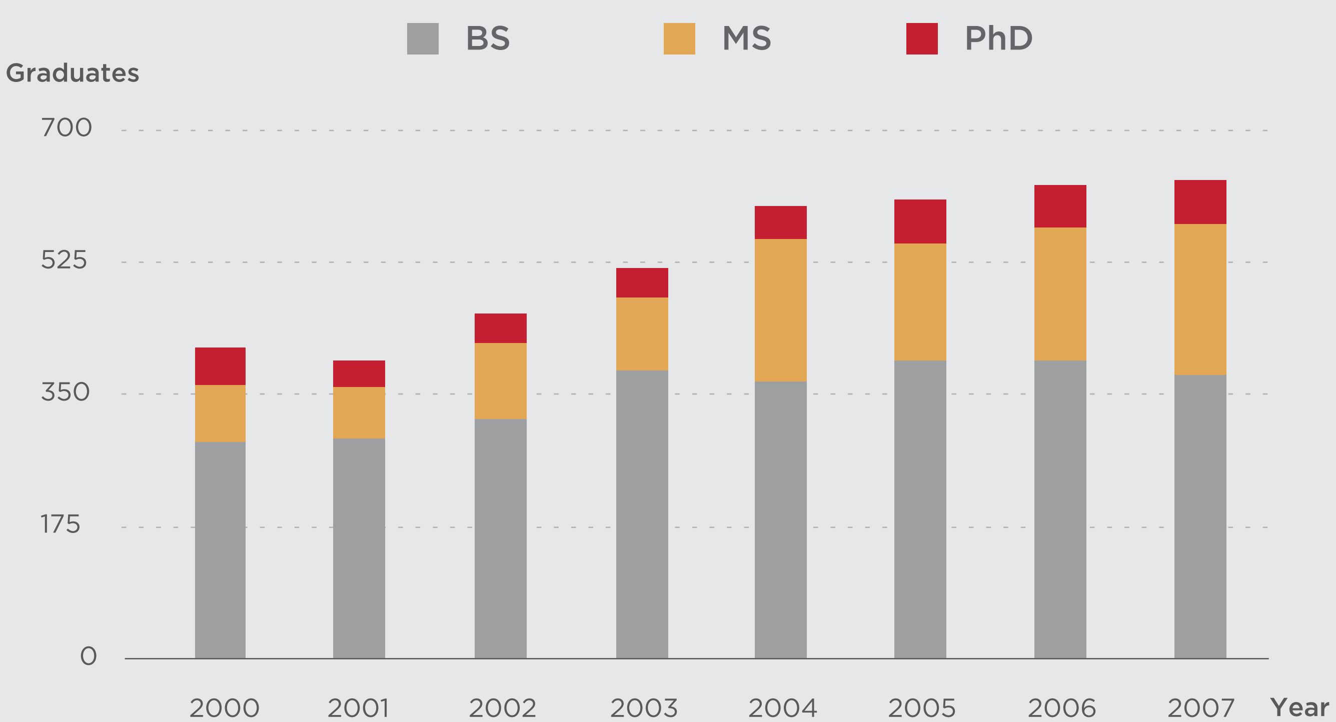
"Engineers would eventually like to harness terahertz frequencies for communication, much faster computing and even for anti-terrorism scanners. Our study is relevant mainly to computers that would use terahertz radiation to run at speeds much faster than today's computers."

Ajay Nahata
Electrical & Computer Engineering

DEGREES AWARDED: 2000–2007

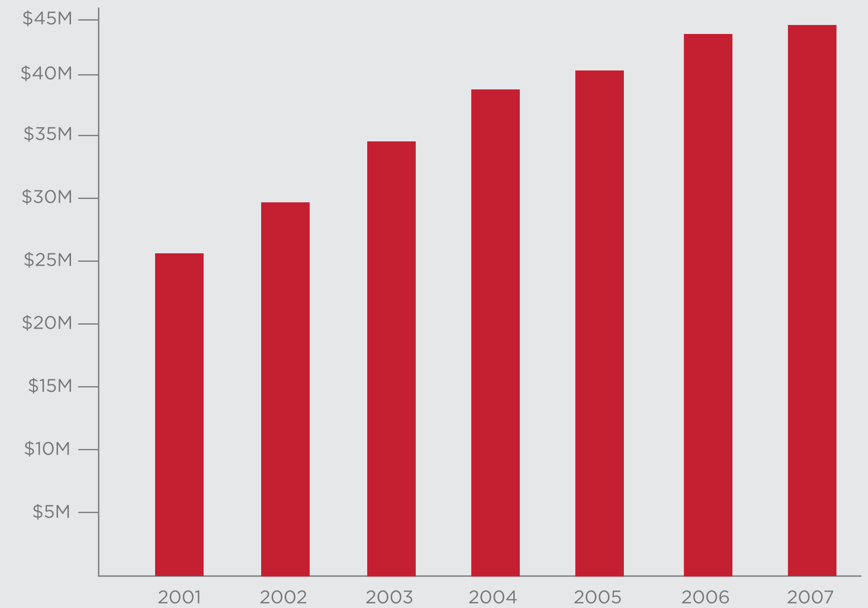


Graduating with Honors:
Seniors in the Honors in Engineering Program receive recognition for their research.

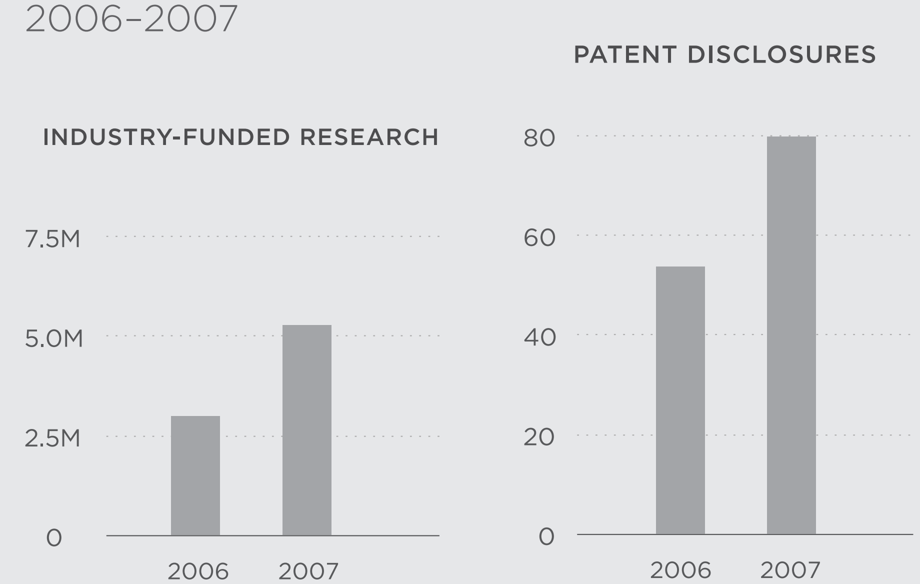


FACULTY SIZE	
217 Full-time Faculty (141 Tenure Track, 9 Lecturing, and 67 Research Faculty)	112 Adjunct Faculty

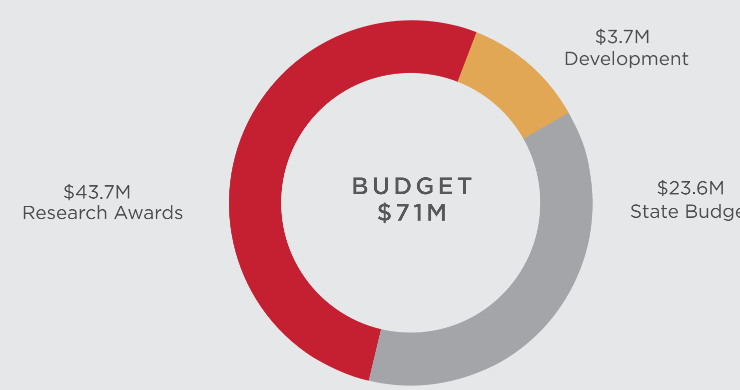
RESEARCH EXPENDITURES: 2001–2007



TECHNOLOGY COMMERCIALIZATION: 2006–2007



BUDGET: 2006–2007



With $44 million annually in external research funding, the *College of Engineering* is a vital component of the University's growing research enterprise and offers a full spectrum of engineering disciplines and research training opportunities.

The University of Utah was recently ranked second in the nation only to MIT at starting companies, according to the Association of University Technology Managers, which ranks public and private research institutions throughout the country. The University launched 20 new companies from technologies developed at the University in 2006, 17 companies in 2007, and 24 companies in 2008. The College of Engineering was responsible for 25 new startup companies from 2006 to 2008.

The University of Utah's intellectual property is managed by its Technology Commercialization Office *(TCO)*. Since 2005, TCO has focused on economic development. TCO has set up a satellite office in the College of Engineering to direct the College's extensive technology commercialization activities.

Our highly interdisciplinary research environment has enabled faculty to respond to emerging needs in such diverse areas as visualization and graphics, energy, robotics, software engineering, advanced electronics, neuroprosthetic development, new construction and transportation technology, photonics and nanotechnology.

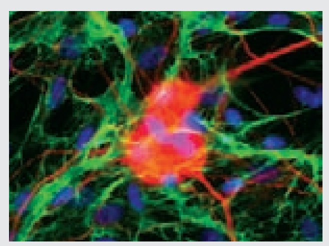
RESEARCH INSTITUTES

- The Brain Institute
- Institute for Clean and Secure Energy (ICSE)
- Scientific Computing and Imaging (SCI) Institute
- Energy and Geoscience Institute (EGI)
- Cardiovascular Research and Training Institute (CVRTI)
- Center for High Performance Computing

RESEARCH CENTERS

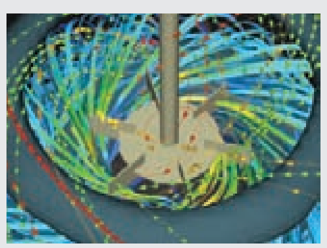
- Center for Excellence in Nuclear Technology, Engineering, and Research (CENTER)
- The Keck Center for Tissue Engineering (KCTE)
- Nanofabrication Laboratory
- Center for Integrative Biomedical Computing
- Center for Controlled Chemical Delivery
- Petroleum Research Center
- Rocky Mountain Center for Occupational and Environmental Health
- Quality and Integrity Design Engineering Center
- Utah Center for Advanced Imaging Research
- Moran Eye Center

COLLEGE OF ENGINEERING DISCIPLINES

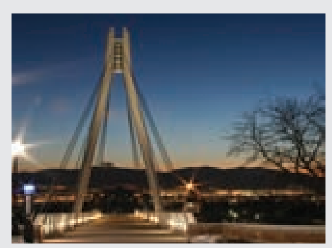


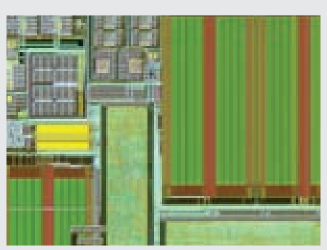
Bioengineering

Chemical Engineering



Civil & Environmental Engineering



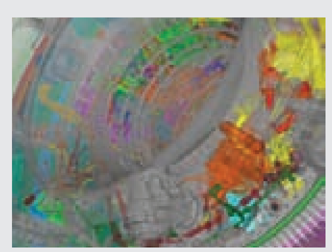


Electrical & Computer Engineering

Materials Science & Engineering

Mechanical Engineering

The School of Computing



College of Engineering

Engineering National Advisory Council

Photo Credit: Pixar Animation Studios

Edwin E. Catmull, Ph.D., President of Walt Disney and Pixar Animation Studios, is the new Chair of the University of Utah Engineering National Advisory Council. Catmull is a founding member of the Council, which was established in 2001 to support and guide the strategic direction of the college.

A member of the Academy of Motion Picture Arts and Sciences and the National Academy of Engineering, Catmull earned B.S. degrees in computer science and physics and a Ph.D. in computer science from the University of Utah.

Dr. Edwin Catmull
(Chair)
President
Walt Disney and Pixar Animation Studios

C. Ross Anderson
President and CEO
AAA Engineering & Drafting

Kline P. Barney, Jr.
Kline Barney Engineers, LLC

Harold Blomquist
President and CEO
Simtek Corporation

Dr. Don R. Brown
President
PartNET

Craig S. Carrel
President
Team One Plastics

Paul B. Clyde
Executive VP and COO
Clyde Companies, Inc.
President
W. W. Clyde & Co.

Clair F. Coleman
Retired President and CEO
Questar Pipeline (formerly Mt. Fuel Resources)

Dr. David A. Duke
Retired–Vice Chairman
Corning Corporation

Dal Freeman, P.E.
Park Engineer
Lagoon Corporation

Mark Fuller
Chairman and CEO
WET Design

Sidney J. Green
Retired–Chairman and CEO
TerraTek, Inc.

Paul J. Hirst, P.E.
President and CEO
Caldwell Richards Sorensen

Dr. James F. Jackson
Retired–Deputy Director
Los Alamos National Laboratory

David S. Layton
President and CEO
The Layton Companies

A. Tee Migliori
President
ADC Technologies, Inc.

Harold W. Milner
Retired–President
Kahler Corporation

Susan D. Opp
President & General Manager
L-3 Communications Systems-West

Brad. J. Overmoe
President
Red Hanger Cleaners

Dr. Christopher H. Porter
Medical Genesis, Inc.

Shane V. Robison
Executive Vice President & Chief Technology & Strategy Officer
Hewlett-Packard

Lynn S. Scott
Retired–Group Vice President and Division General Manager
Parker Hannifin

Michael W. Soulier
Retired–Director Human Resources
E.I. Du Pont De Nemours & Company

Dr. Gregory P. Starley
Sr. Advisor, Business Development
International Division
Devon Energy Corporation

Dr. Gerald B. Stringfellow
Distinguished Professor
U of U Dept. of Electrical & Computer Engineering and Materials Science & Engineering

Dr. Randal R. Sylvester
Chief Technologist
L-3 Communications Systems-West

J. Howard Van Boerum, P.E.
President Emeritus
Van Boerum & Frank Associates, Inc.

Robert B. Wiggins
President
Quartzdyne, Inc.

Kim Worsencroft
Entrepreneur

Utah: AN INSPIRING PLACE TO LIVE AND LEARN

In addition to the attractions of a great university and medical research center, faculty and students at the University of Utah find inspiration in its beautiful mountain setting and the urban amenities of Salt Lake City. Just a short drive from an international airport with direct flights to Paris, Salt Lake City is situated in a large valley sheltered by the Wasatch Mountains to the east and the Oquirrhs to the west. On average, Utah's mountains are among the highest in the U.S., providing a dramatic and exciting playground for outdoor and skiing enthusiasts, just minutes from campus. Salt Lake's cultural scene includes symphony, ballet and opera companies, and nearby Park City is the home of the Sundance Film Festival and annual arts festival. Sports fans enjoy Jazz basketball, Real Salt Lake soccer, as well as AAA Bees baseball and IHL Grizzlies hockey.

A wonderfully livable city, Salt Lake is one of the most commuter friendly urban settings with a multi-modal transportation network that includes light rail, commuter trains and buses. Salt Lake's TRAX light rail system, with nearly 60,000 daily riders, links the University of Utah with valley neighborhoods and downtown Salt Lake. New links to the Salt Lake International Airport are in the planning stage.

Salt Lake is also the gateway to some of the world's most stunning national parks including Bryce Canyon, Arches, Canyonlands, Cedar Breaks and Zion National Parks, all located within a five hour drive to the south. Visitors from around the world are attracted by the dramatic and ever changing geology of the Colorado plateau, providing rich opportunity for exploration by hikers, rock climbers and white water rafters. Five hours to the north in neighboring Wyoming are Grand Teton National Park and the south entrance to Yellowstone National Park.

1 Engineering Students Living & Learning Community in the former 2002 Winter Olympic Village.

2 College of Engineering campus.

3 Snowboarding in Big Cottonwood Canyon. Photo courtesy Utah Office of Tourism (Howie Garber).

4 Park City Jazz Festival. Photo courtesy Utah Office of Tourism (Steve Greenwood).

5 Salt Lake Valley at night. Photo courtesy Utah Office of Tourism (Jerry Sintz).

6 "Thor's Hammer" in Bryce Canyon National Park. Photo courtesy Utah Office of Tourism (Frank Jensen).

7 Fly fishing at Bear River. Photo courtesy Utah Office of Tourism (Frank Jensen).

8 Sunset at Cedar Breaks National Monument. Photo courtesy Utah Office of Tourism (Tom Till).

THE UNIVERSITY OF UTAH

COLLEGE OF ENGINEERING

RESEARCH REPORT 2008

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