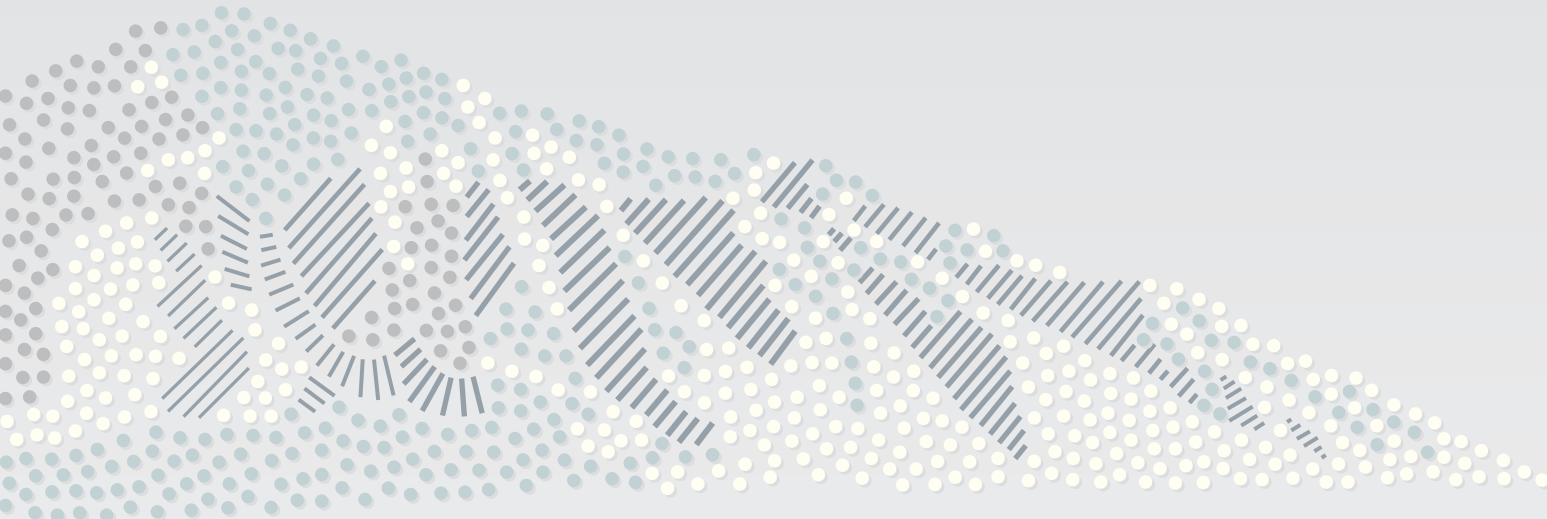
2011 RESEARCH REPORT

COLLEGE OF ENGINEERING



THE UNIVERSITY OF UTAH

Contents

From the Dean

For a dean of engineering in a state with the nation's top-ranked economy for projected job growth, the business headlines from the past 12 months have been nothing short of breathtaking:

"2 Utah tech firms adding jobs; investing more than $1B" (June 21, 2011)

"ATK poised to fire-up new plan, begin hiring" (June 21, 2011)

"EMC brings 500 technical jobs to Utah" (June 20, 2011)

"Utah's NSA spy center will bring 5,000-10,000 construction jobs. Long term staff will include up to 200 IT specialists, mechanical and electrical engineers" (Jan. 7, 2011)

"Merit Medical's $45 million expansion will house 700 new workers in five to 10 years" (Sept. 24, 2010)

"Adobe's Utah Plan includes a $100 million new facility and as many as 1,000 people during the next 20 years" (Aug. 5, 2010)

With each of these companies adding highly skilled technical jobs by the hundreds, the College of Engineering must continue to accelerate its rate of growth to meet the demand for highly qualified engineers, and to keep the economy turning.

Fortunately, the College of Engineering has spent more than a decade ramping up enrollment, faculty and facilities. According to the most recent American Society for Engineering Education (ASEE) Profiles, the College of Engineering is 49th of 360 schools in the size of our undergraduate enrollment, and 48th of 261 schools in graduate enrollment. The number of tenure-track faculty has increased by 50% in the past six years, placing us 37th out of 337 schools.

Working closely with the University of Utah, state and industry leaders, the College of Engineering has a clear vision of its role as a leader of innovation, technology commercialization, and production of engineers and computer scientists. We must continue to provide outstanding talent for companies engaged in fiercely competitive global markets. The quality of our graduates contributes directly to the long-term success of our graduates' employers.

According to Dr. Randall Sylvester, chief technologist for L-3 Communications Systems–West:

"More than 500 employees at the Communication Systems West Division of L-3 Communications in Salt Lake City are graduates of the University of Utah. Our customers compliment us on our technical expertise and this technical competence has allowed our division to grow our business and technology base significantly. The quantity and quality of the engineering graduates from the University of Utah is a key reason for this continued success."

In addition to the U of U's contribution to an outstanding workforce, the faculty have grown engineering research to more than $68 million per year (up from $25 million eight years ago). University research is a major source of technology innovation that benefits companies seeking to maintain a competitive advantage and leads to spin-off companies that create new jobs. The College of Engineering is ranked 36th of 203 schools nationally in total annual research expenditures. The research results are disseminated through publications and technology commercialization so as to have a positive impact on humankind. The College's success in research has contributed to its being ranked among the top 100 Engineering/Technology and Computer Sciences programs by the Academic Ranking of World Universities.

The College of Engineering is fortunate to be at the center of a highly successful strategy of targeted investment in engineering education and research as a magnet for attracting new companies and for supporting existing companies in their efforts to expand. The current strength and dynamism of the Utah economy is a clear indication that the strategy is working. The result is a tremendous sense of optimism and anticipation for the opportunities to advance even further. We hope we have managed to convey at least some of that excitement in the following report.

Richard B. Brown
DEAN, COLLEGE OF ENGINEERING

Building Engineering at the U

The University of Utah continues to make progress on construction of a new, state-of-the-art interdisciplinary research facility that will enhance the U's continued robust program of innovation and technology development. The James L. Sorenson Molecular Biotechnology Building — a USTAR Innovation Center, will unite the health sciences campus and main campus to accelerate research at the interfaces of medicine, engineering, pharmacy and science. The building will foster the connection between research, entrepreneurship and industry. Construction of the 208,000 square-foot facility should be complete near the beginning of 2012.

The building will support dozens of faculty researchers, administrative and laboratory personnel in a number of lab and research spaces, including facilities for nanofabrication, small-animal imaging, and advanced optical imaging, along with a vivarium, and neuroscience and biotechnology labs.

The energy-efficient building (planned for LEED Gold Certification) should reduce energy use and cost from current laboratory code requirements by at least 40 percent. The building is also designed to be as vibration-proof as possible to ensure high-sensitivity scientific instruments work in an optimal fashion. The building's floors are engineered for little structural movement or vibration when anchored to its stout footings, foundation, columns and walls.

The building is funded by a $15 million cornerstone gift from the Sorenson Legacy Foundation, $100 million from the state of Utah, and private donations. USTAR (Utah Science Technology and Research Initiative) is a long-term economic development initiative to promote Utah-based technologies and research for commercialization.

NEW FACULTY MEMBERS

Orly Alter
Bioengineering and SCI Institute

EDUCATION:
Ph.D., applied physics, Stanford University

PREVIOUS POSITION:
Assistant professor of biomedical engineering, University of Texas, Austin

RESEARCH INTERESTS:
Using mathematical frameworks to model large-scale molecular biological data, such as DNA microarray data

Brittany Coats
Mechanical Engineering

EDUCATION:
Ph.D., bioengineering, University of Pennsylvania

PREVIOUS POSITION:
Postdoctoral research associate, Department of Bioengineering, University of Pennsylvania

RESEARCH INTERESTS:
Characterizing linear and non-linear material properties of skull and brain tissue to identify injury tolerances in children

Mathieu Francoeur
Mechanical Engineering

EDUCATION:
Ph.D., mechanical engineering, University of Kentucky

PREVIOUS POSITION:
Research assistant, University of Kentucky

RESEARCH INTERESTS:
Near-field radiative transfer applied to thermal radiation, thermophotovoltaic power generation, and optical characterization of nanoparticles

Luis Ibarra
Civil & Environmental Engineering

EDUCATION:
Ph.D., structural engineering, Stanford University

PREVIOUS POSITION:
Senior research engineer, Southwest Research Institute, Center for Nuclear Waste Regulatory Analyses, Southwest Research Institute

RESEARCH INTERESTS:
Structural engineering, performance-based design with emphasis on the collapse limit state, seismic risk assessment, and aging effects on structural performance

Manoranjan Misra
Chemical Engineering

EDUCATION:
Ph.D., metallurgy, University of Utah

PREVIOUS POSITION:
Professor, Materials Engineering Division, University of Nevada at Reno

RESEARCH INTERESTS:
Photoelectrochemical hydrogen generation, hydrogen storage using CNT and titania composites, materials for high-temperature nuclear reactors, nanotube and nanowire devices

Bart Raeymaekers
Mechanical Engineering

EDUCATION:
Ph.D., mechanical engineering, University of California, San Diego

PREVIOUS POSITION:
Postdoctoral fellow, Los Alamos National Laboratory

RESEARCH INTERESTS:
Ultrasonic sensor technology for energy and biomedical applications; magnetic recording technology

Thomas Schmid
Electrical & Computer Engineering

EDUCATION:
Ph.D., electrical engineering, University of California, Los Angeles

PREVIOUS POSITION:
Networked & Embedded Systems Laboratory, University of California, Los Angeles

RESEARCH INTERESTS:
Wireless communication, sensor networks, routing strategies and embedded systems

David Schurig
Electrical & Computer Engineering

EDUCATION:
Ph.D., physics, University of California, San Diego

PREVIOUS POSITION:
Adjunct assistant professor, electrical & computer engineering, North Carolina State University

RESEARCH INTERESTS:
Design, analysis and fabrication of metamaterials in frequency ranges from megahertz to petahertz; transformation design of devices implementable with metamaterials

Haori Yang
Civil & Environmental Engineering
Nuclear Engineering

EDUCATION:
Ph.D., nuclear engineering and radiological sciences, University of Michigan, Ann Arbor

PREVIOUS POSITION:
Research scientist, Canberra Industries

RESEARCH INTERESTS:
Detector design and development, radiation imaging and monitoring systems, waste assay techniques, nuclear instrumentations and control systems

Water Management

PLANNING AND ENGINEERING SUSTAINABLE, RESILIENT WATER RESOURCE SYSTEMS

Covering more than 70 percent of the earth, water is essential to all forms of life. Water plays an important role in the world economy as civilization has typically grown and flourished around rivers and major waterways.

A clean and secure water supply is perhaps the most vital component of public health. Destruction of water supply, stormwater management and wastewater disposal infrastructure after catastrophes, such as earthquakes or floods, and their deterioration over time poses severe challenges to the affected population, including waterborne diseases that can be life-threatening, excessive operation and maintenance costs and significant environmental impacts.

Steven Burian, associate professor of civil and environmental engineering, is working on the issue of safe water by improving the resiliency of water systems in the United States and communities around the world. He uses computer modeling, simulation and data analysis to quantify implications of water infrastructure changes, such as decentralization, on system sustainability and to determine impacts of climate change on system resiliency. He seeks to develop and evaluate new designs and technologies that can improve water infrastructure system resiliency.

Alfred Kalyanapu (holding a graphics processing unit) and Steven Burian stand in front of one of their flood modeling simulations.

Integrated Urban Water Management

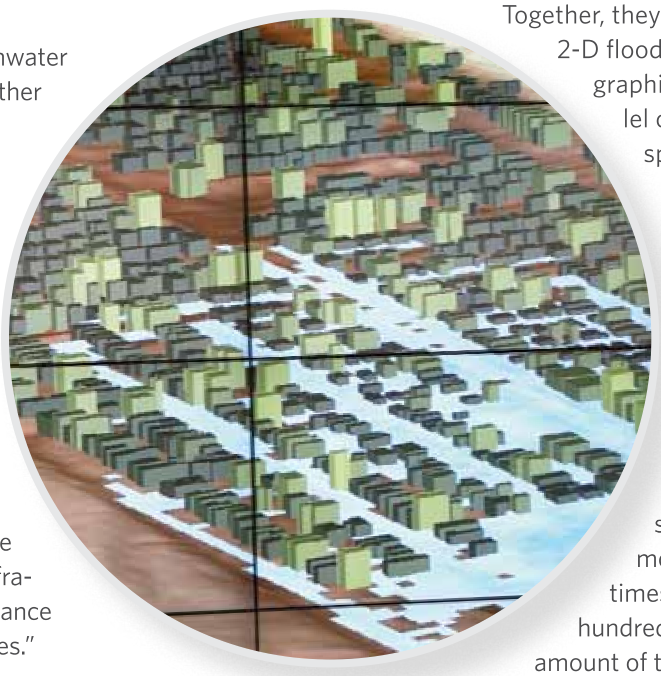
One of Burian's projects seeks new ways to plan, design and manage urban water supply, stormwater, and wastewater collection and disposal as an integrated system. "This includes determining the implications of low-impact urban water infrastructure integration development and decentralization on environmental impact, energy demand, and life-cycle costs," he says. "In general, we seek to find a balance of centralization and decentralization, conservation and reuse, and resiliency and cost for urban water management."

Decentralization involves distributing the management of a resource throughout the system. Centralized urban water management, which involves large treatment facilities and extensive pipe and sewer networks, is reaching its limits due to rapid urban growth. In the future, the sustainability will be further challenged as urban water infrastructure systems are stretched further and resources become scarcer. Decentralized urban water management is one possible solution. It incorporates specific practices such as rainwater harvesting, graywater treatment, water reuse, stormwater infiltration and ecological wastewater treatment to distribute the management of water throughout the system.

"The difficulty is quantifying the implications to public health risk, cost, and the environment from these shifts and ultimately finding the most effective combination of centralized and decentralized elements," says Burian.

Burian and his team are working with cities across the country, and specifically with the City of San Diego and the American Society of Civil Engineers, to develop rainwater harvesting programs (accumulating and storing rainwater for use at the point of consumption) as one component of a decentralized urban water system. He is also leading a national committee in the development of guidelines for use of rainwater harvesting for stormwater management. "We are using simulation tools to show what a cost-effective size cistern would be and what would be the impacts on storm water runoff control and water supply," he says. "We also demonstrate the sustainability and costs of the program and the benefits."

In some states, including Utah, rainwater harvesting, graywater reuse, and other decentralized water management techniques are constrained by water rights. "Recent legislation in Utah has made rainwater harvesting possible within specified constraints," says Burians. "Other states have gone much further to the point of requiring installation of rainwater harvesting and promoting decentralized stormwater management concepts, but there is uncertainty about what effect these changes may have on the water infrastructure system cost and performance as well as the receiving water bodies."



Although it is difficult to determine the best approach to creating a decentralized urban water system, Burian says that new technologies can be developed to tailor a system to meet the area's climate and geographical needs.

Flood Modeling and Consequence Assessment

For nearly a decade, Burian and his group have worked with researchers at Los Alamos National Laboratory in New Mexico to develop new approaches and tools to help analyze urban water infrastructure and to determine impacts of natural hazards, such as floods. One recent development has been the creation of faster flood computer modeling integrated with geospatial analysis and data management tools. "Our goal is to improve our ability to project flood impacts and quantify resiliency of water infrastructure to floods," he says. "This will lead to improved approaches to plan and configure urban areas and the water infrastructure networks to be more sustainable."

With more than 2.8 billion of the world's population living within 10 miles of rivers, floods are one of the more frequently occurring, high-impact natural disasters. Every year on average approximately 200 million people in more than 90 countries are affected by catastrophic flooding. Between 1980 and 2000, there were more than 170,000 deaths reported worldwide due to floods—and this statistic is before the 2004 Indian Ocean earthquake and tsunami that is estimated to have killed more than 230,000 people or the recent earthquake and tsunami in Japan that resulted in the loss of thousands of lives. "This problem with flooding is being aggravated by population growth and movement into high-risk coastal and riparian areas, as well as climate change," says Burian.

Burian and one of his Ph.D. students Alfred Kalyanapu have partnered with computer science professor Charles Hansen from the University of Utah's Scientific Computing & Imaging (SCI) Institute to develop faster flood modeling. Together, they have integrated Burian's group's 2-D flood modeling capability with SCI's graphics processing unit (GPU) parallel computing approach. GPUs are specialized hardware that rapidly control memory to accelerate the building of images when performing simulations. Parallel computing allows computations to run faster by running parallel to one another, instead of sequentially.

"Before we integrated GPUs, it would take hours just to do one simulation," says Burian. "This fast model has reduced our model run times to seconds and permitted us to do hundreds of simulations in a much shorter amount of time to project flood impacts and analyze impacts faster than ever before."

Using the fast modeling approach, Burian is working with Los Alamos National Laboratory to determine flood risk from hurricanes and other disasters in particular regions and cities. When hurricanes are forecasted, there is usually only a few days of lead time to simulate multiple possible flooding scenarios. With fast modeling, analysts can potentially run thousands of scenarios in minutes. "It's important to be able to look at a potential flood area and simulate what might happen to the communications, energy, water and transportation infrastructure, which will help us assess potential damage and help guide policy to improve system resiliency," says Burian.

Other projects in Burian's group includes one funded by NASA that uses global hydrologic simulations and satellite precipitation observations to study how urban areas influence regional climates, the water cycle and flood risk. He is also studying the interrelationship between water system services and energy demand.

High-Performance Computing

IMPROVING COMPILERS AND PROGRAMMING FOR FASTER, BETTER PERFORMANCE

High-performance computing, once exclusively devoted to scientific computing challenges conducted in national laboratories, has now become essential for solving all sorts of computationally intensive problems in automotive, pharmaceutical, financial and life science industries, climate research, health sciences and the military. It is a multidisciplinary field that combines the underlying problem to be solved with computational methods and parallel computer system design with a goal to achieve faster, more efficient computing in less time.

Mary Hall, associate professor in the School of Computing at the University of Utah, is focused on improving application performance for current and future high-end computing systems. Her research group is developing optimization technology for compilers (computer software that translates source code from a computer language into another computer language that the computer hardware understands). This technology exploits performance-enhancing features of modern computer architectures (the design and operational structure of computer systems), including multi-core microprocessors and graphics processing units (GPUs). While originally developed for realistic graphics in computer games, GPUs are now widely used in high-performance scientific and engineering computing.

'Extremescale' Supercomputing

Hall is working with a group of universities and companies that have recently been awarded a four-year, $25 million research grant for the Ubiquitous High-Performance Computing program funded by the Defense Advanced Research Projects Agency (DARPA). Led by NVIDIA Corporation, the group is developing a complete design for Echelon, an innovative example of a new generation of computing systems, called "extremescale" supercomputers, which are projected to be 500 times more powerful than today's fastest supercomputers. DARPA—the research and development office for the U.S. Department of Defense—wants the technology ready by 2018.

"The technologies we propose to develop will enable construction of systems that achieve energy efficiency, are easy to program and are resilient in the face of both component failures and malicious attacks," says Hall, the leader of the U of U group whose role is "to contribute to the programming model design and compiler technology for the proposed architecture" in collaboration with other teams from outside the U.

Specifically, Hall's group is developing the autotuning technology that will systematically map application code to make efficient use of diverse architectures. An autotuning compiler generates a set of alternative implementations of a computation and uses empirical measurement to select the best-performing solution. "The complexity of today's parallel architectures creates a huge burden for application programmers to tune the code they write," says Hall. "Our compiler can work automatically or collaboratively with programmers to map their code to new generations of computer systems, and, in some cases, produce results far better than manual tuning."

The technology is being developed for large systems such as supercomputers and data centers, rather than for desktop computers. The resulting Echelon design "will provide at least 50 times greater energy, computing and productivity efficiency, which will slash the time needed to design and develop complex computing applications," according to DARPA.

"However, with more powerful computers comes more issues," Hall says. "We have to take into account that there will be more components that may break, more complex software that may fail, more parallel processors to keep busy and greater energy needs."

Hall says the group will conduct a series of studies to estimate where computer technology will be in 2018 so they may anticipate future needs.

The University's of Utah's portion of the project accounts for approximately $1.2M of the total project. Other members of the project include Cray Inc., Oak Ridge National Laboratory, UC Berkeley, Stanford University, Georgia Tech, the University of Texas and the University of Pennsylvania.

NSF and DOE Computing Projects

Hall's research is also important to other agencies in supporting high-end applications on today's computing systems. Last year, Hall received a two-year

NSF grant to develop a compiler-based autotuning optimization and code generation framework that will provide high performance across a range of computer architectures.

Because computer architectures are constantly changing, programmers must write software code at a relatively "low" level to operate efficiently on specific architecture platforms. Simplified code creates inefficiencies and does not allow the programmer to have as much control over computer performance. "Computer architectures are going through rapid change and experimentation with different ideas," says Hall. "What works well for one may not work well for others."

Hall is developing an abstraction tool that programmers can use to gain very high performance without having to worry about the details of specific computer architectures. An abstraction tool hides or removes unnecessary details so that programmers can focus on a few concepts at a time.

"Today, a programmer may write one program for a particular platform, but it may not translate well to different platforms," says Hall. "With our abstraction tool, the goal is for the programmer to write software that performs at a high level on a range of multi-core and many-core architectures, not just the one which they're using today."

This autotuning system is also used to tune applications for high-end systems and supercomputers for the U.S. Department of Energy (DOE). This research involves developing technology and working closely with DOE application scientists to tune their production code that executes on supercomputers that are among the fastest in the world. The DOE uses these software tools for projects such as climate modeling or studying nuclear fusion.

"The Department of Energy wants computer science research that makes an impact on the science they do," she says. "Because they do large-scale simulations, they are always looking for faster, better, more effective tools."

Mary Hall

A CUDA CENTER OF EXCELLENCE

For the past three years, Mary Hall, associate professor of computer science, has been teaching a new class in the School of Computing, called Parallel Programming for GPUs, that involves training students from across campus to use special-purpose hardware originally designed for graphics and games to solve general-purpose computing problems. The technology for the class was donated by NVIDIA, which in 2008 named the University of Utah as a Compute Unified Device Architecture (CUDA) Center of Excellence for its pioneering work in parallel computing.

The CUDA Center of Excellence uses GPU technology to make significant advances in a number of scientific applications, including seismic data processing and visualization, MRI and diffusion tensor image reconstruction, cardiac electrical wave propagation simulation, combustion and fluid dynamics simulation, and several projects in large-scale scientific visualization.

Interfacing with the Brain

ADVANCED MICROSYSTEMS FOR IMPROVED NEURAL MEDICAL SOLUTIONS

Florian Solzbacher holds a neural interface device. A wireless version is pictured on the next page.

An artificial limb that is controlled by an amputee's thoughts; cochlear implants that allow the deaf to hear; retinal implants that give sight to the blind; and cognitive implants that alleviate chronic pain, allow the paralyzed to walk, or provide relief from Parkinson's disease or epilepsy. These are just some of the advances that one day may be possible through implantable neural devices that can substitute for a motor, sensory or cognitive function that has been damaged as a result of injury or disease.

"We're talking about small electronic neural interface devices—micro- and nano-systems—that can enable better personalized health care and improved quality of life," says Florian Solzbacher, associate professor of electrical and computer engineering at the University of Utah.

Solzbacher is part of a multi-disciplinary team of engineers and researchers that is focused on developing such devices. A core goal of his work is developing next generation microsensors, micro-actuators, materials and fabrication technologies for biomedical and health care applications.

Solzbacher proposed and developed the first fully integrated wireless neural interface based on the Utah Electrode Array, a pill-sized device containing 100 tiny electrodes that was invented by distinguished professor of bioengineering Richard Normann. Solzbacher has since developed this system integration approach into a technology platform that can be applied to many different penetrating and non-penetrating electrode types.

Clinical Trials for Wireless Neural Devices

Through Blackrock Microsystems—a company founded by Solzbacher—these wireless neural interface devices are currently being tested for regulatory approval in preparation for pilot clinical trials involving just a few patients who suffer from paralysis or amputation. The patients will be fitted with wireless devices in the brain or nerves to help them gain control over a wheelchair or a prosthetic device, the first of which will be a next-generation prosthetic arm developed under the DARPA (Defense Advanced Research Projects Agency) Revolutionizing Prosthetics Program (RP 2009) by Johns Hopkins Applied Physics Laboratory. The devices are made to operate inside the "harsh environment" of the human body without breaking down or causing a harmful response.

"The wireless neural devices have the potential for a large range of applications," he says. "In our studies right now, we are primarily looking at safety and efficacy. Once that is complete, then we think about potential products for patients."

Although the trials are mainly about safety and about studying long-term failure rates, Solzbacher says some of the patients in past studies using wired versions of the devices have regained some motor control that they had lost.

"We have been able to show that these devices have improved a patient's communication, mobility and ability to participate in the world, although we have not completely restored all of their functions yet," he says. "Plus, we know that because it is implanted inside the body that at some point the device will fail. Ideally we want devices that can last a lifetime, but realistically now we're looking at trying to make them go for at least 10 years, which would be a huge accomplishment."

A Better Artificial Arm

The DARPA project, which uses Solzbacher's neural interfaces, is an artificial arm research project sponsored by the Department of Defense in a bid to help wounded soldiers. The artificial arm is designed to be life-like and includes a modified Utah Electrode Array that records brain signals and stimulates the brain to allow the artificial arm to move naturally in response to a patient's thoughts, as well as give the patient a sense of touch.

Solzbacher is developing and fabricating the components for the array and is encapsulating the interface devices to make them durable and safe for implantation. Researchers at other institutions are developing the prosthetic itself. The project is currently in Phase 3 development and within about a year will begin early clinical trials in which a few patients will be fitted with the prosthetic.

The Utah array technology also plays a role in a project that may allow locked-in patients to "speak" with their thoughts. An array of 16 nonpenetrating microelectrodes were developed to sit on speech areas of the brain without poking into it. In a recent study headed by Bradley Greger, assistant professor of bioengineering at the University of Utah, the "microECoGs" read brain signals while a volunteer patient with severe epileptic seizures repeated one of 10 words. Researchers recorded the signals and looked for patterns that correspond to the different words by analyzing changes in strength of different frequencies within each nerve signal. Depending on the speech area of the brain, they were able to achieve up to 90 percent accuracy in decoding the brain signals into words. The study also involved PhD student Spencer Kellis from electrical engineering, Richard Brown, dean of the College of Engineering, and Paul House, assistant professor of neurosurgery.

"We have recently submitted a proposal together that will see us build a custom wireless neural interface for chronic use in patients," says Solzbacher.

BLACKROCK TECHNOLOGY

In addition to his own research, Professor Florian Solzbacher's Blackrock Microsystems company acts as a service provider for on and off-campus industrial institutional research and development partners. His company provides novel neural research tools such as implantable devices, electronics, equipment, tools and software to universities, laboratories, hospitals and companies worldwide.

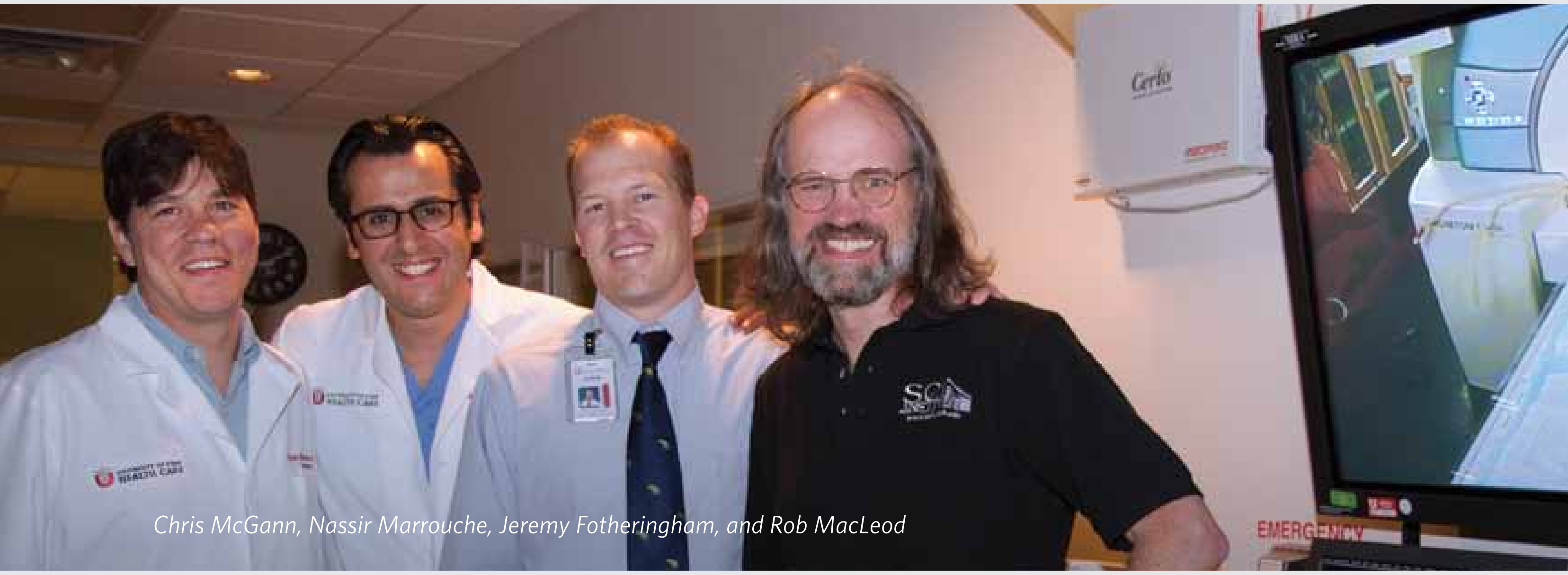
The company draws on a legacy of high-tech innovation that began with Bionics, a spin-off from the University of Utah in 1997 co-founded by Professor Richard Normann. The company was later bought by Cyberkinetic Neurotechnologies. In 2008, the research business part of the company was acquired by Blackrock.

"Blackrock is unique in that it is not a classical startup company," Solzbacher says. "It's the only company I am aware of that is providing FDA-approved devices and electronics that allow you to tap into the nervous system with an implantable device for patients who need it."

The company recently launched Blackrock Neuromed, which delivers "the most sophisticated EEG and single-cell recording systems to clinicians and researchers worldwide," says Solzbacher. Other companies co-founded by Solzbacher include Blackrock Sensors and First Sensor Technology.

The Heart of the Matter

INNOVATIVE IMAGING TECHNOLOGY TO IMPROVE TREATMENT FOR A



Chris McGann, Nassir Marrouche, Jeremy Fotheringham, and Rob MacLeod

Researchers in the University of Utah College of Engineering are working with cardiologists and radiologists to transform the treatment of heart rhythm disorders, which abnormally affect the electrical activity of muscles in the heart. The most common arrhythmia is atrial fibrillation, which affects at least 2.5 million Americans and leads to more than 66,000 deaths a year in the U.S. By 2050, the incidence of atrial fibrillation is expected to double to 5 million Americans.

In atrial fibrillation, the right and left atria of the heart lose their synchronization and beat erratically and inefficiently. While usually not life-threatening in its initial stages, the condition reduces the pumping capacity of the heart and elevates heart rate. Over time the condition can lead to a stroke—15 percent of all strokes are caused by atrial fibrillation.

Although there are medications to treat atrial fibrillation, over time these drugs often become less effective at controlling stray electrical impulses and are also poorly tolerated by many patients. One intervention that can permanently suppress atrial fibrillation without the use of supplemental drugs is a procedure called radiofrequency catheter ablation—in which a catheter with an energy-emitting probe is inserted into a vein and threaded into the heart to direct radiofrequency energy directly to trouble spots. The heat from the probe creates scar tissue in the heart, which eliminates erratic electrical signals.

However, the treatment is not always successful. Pre-existing fibrosis in the left atrium can hinder the ability to effectively burn away electrically defective tissue. In addition, doctors historically have had no way to tell the severity of the disease or pinpoint the exact locations of the troubled tissue, making it challenging to determine whether all of the problem spots have been treated.

Using MRI for Atrial Ablation

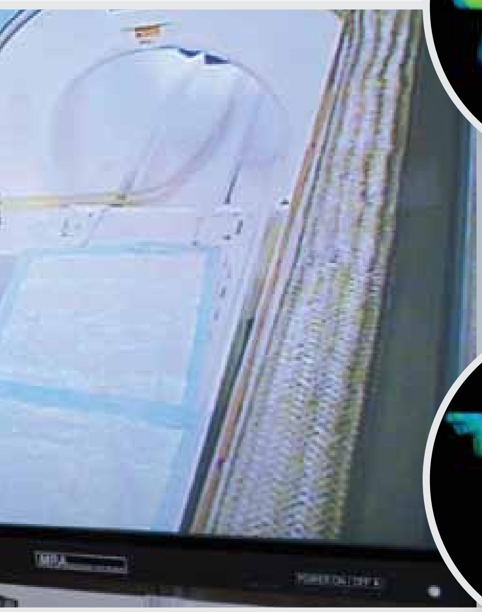
University of Utah researchers are seeking to improve the success and safety of atrial ablation through advances in magnetic resonance imaging (MRI). Imaging specialists at the U have developed new ways of using MRI to visualize the walls of the atria, a task previously considered almost impossible in a beating heart.

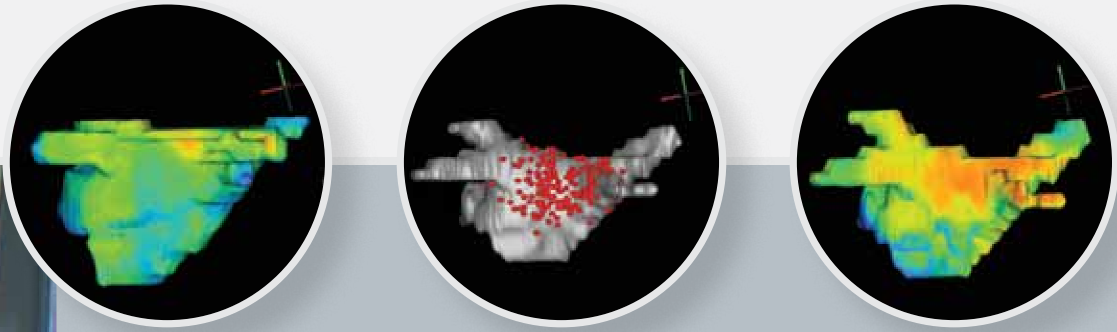
"MRI has the potential to reveal important data about the condition of heart tissue before and after an ablation," says Rob MacLeod, associate professor of bioengineering and a faculty member of the Scientific Computing and Imaging Institute (SCI) and the Cardiovascular Research and Training Institute (CVRTI). MacLeod is on the image analysis and processing team at SCI developing the software technology that allows doctors to get the most accurate information from MRIs.

"The U is at the forefront of developing better imaging techniques and analysis in conjunction with MRI," he says. "This can show the physicians whether a patient has too much atrial fibrosis to be a good candidate for ablation. MRI also helps after an ablation to show where scar tissue is forming."

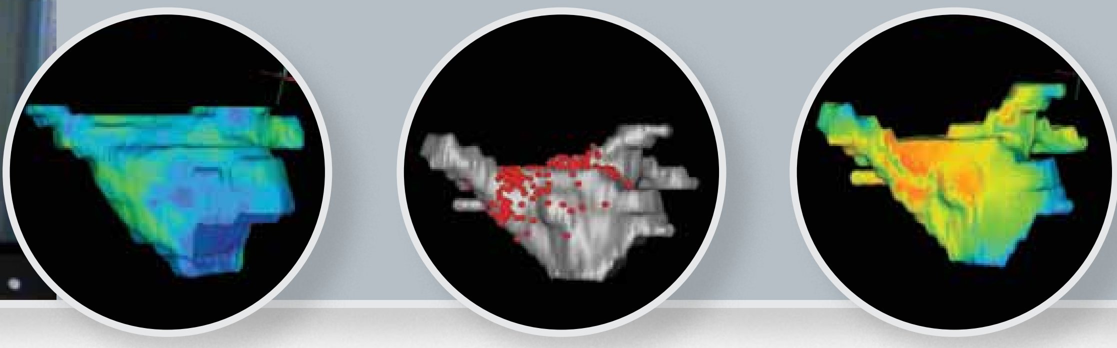
The U's research team was formed after cardiologist Nassir Marrouche came to the University of Utah and learned of the advancements SCI and the Utah Center for Advanced Imaging Research (UCAIR) were making in computing, imaging and visualization. Recognizing the possibilities MRI could offer for ablation therapy, Marrouche founded the U's Comprehensive Arrhythmia Research & Management Center (CARMA) in 2009, leading a team of researchers who are conducting the world's most innovative research on the use of MRI to treat atrial fibrillation.

ATRIAL FIBRILLATION





An example of multiple imaging modalities used by the CARMA team to monitor clinical outcomes of atrial ablation. Pre-ablation MRIs of the left atrium are shown on the left, center images display sites of ablation lesions, and MRIs on the right show regions of scarring after ablation.



The executive committee leadership of CARMA includes Marrouche, MacLeod, radiologist Dennis Parker (director of UCAIR), cardiologist Chris McGann, and hospital administrator Jeremy Fotheringham. Other members of the interdisciplinary research team include bioengineer Edward Hsu and radiology researchers Edward DiBella, Eugene Kholmovski and Rock Hadley. Computer science professor Ross Whitaker, another member of SCI, helped develop the image processing software that is essential for the project.

Personalizing Treatment for Each Patient

Marrouche performs pre-ablation MRIs in his patients to obtain 3-D images of the heart that help him map the location and extent of diseased tissue. The cardiology team quickly recognized that atrial walls in one patient look different from another. Software developed at SCI allowed the team to visualize and quantify these differences—including atrial wall thickness, structure, shape and composition—in each individual patient.

"The results were striking and allowed us to create a method to identify and measure regions of the heart most altered by atrial fibrillation," says MacLeod. "The notion of personalized medicine is very important because there is no 'one size fits all' when it comes to treatment."

The SCI software allowed doctors to design a classification system to help guide personalized treatment for each patient. Patients with high scores in the "Utah Classification Scheme" make poor candidates for ablation since their disease has progressed too far for current ablation techniques. The focus then turns to managing the disease with medication. Patients with low Utah scores have a higher likelihood of success and are treated more aggressively with ablation. "When we first started this project, it would take 10 hours to image, map and analyze a patient's heart," says MacLeod. "Today, it can be done in 20 minutes. That's the difference computing and software can make."

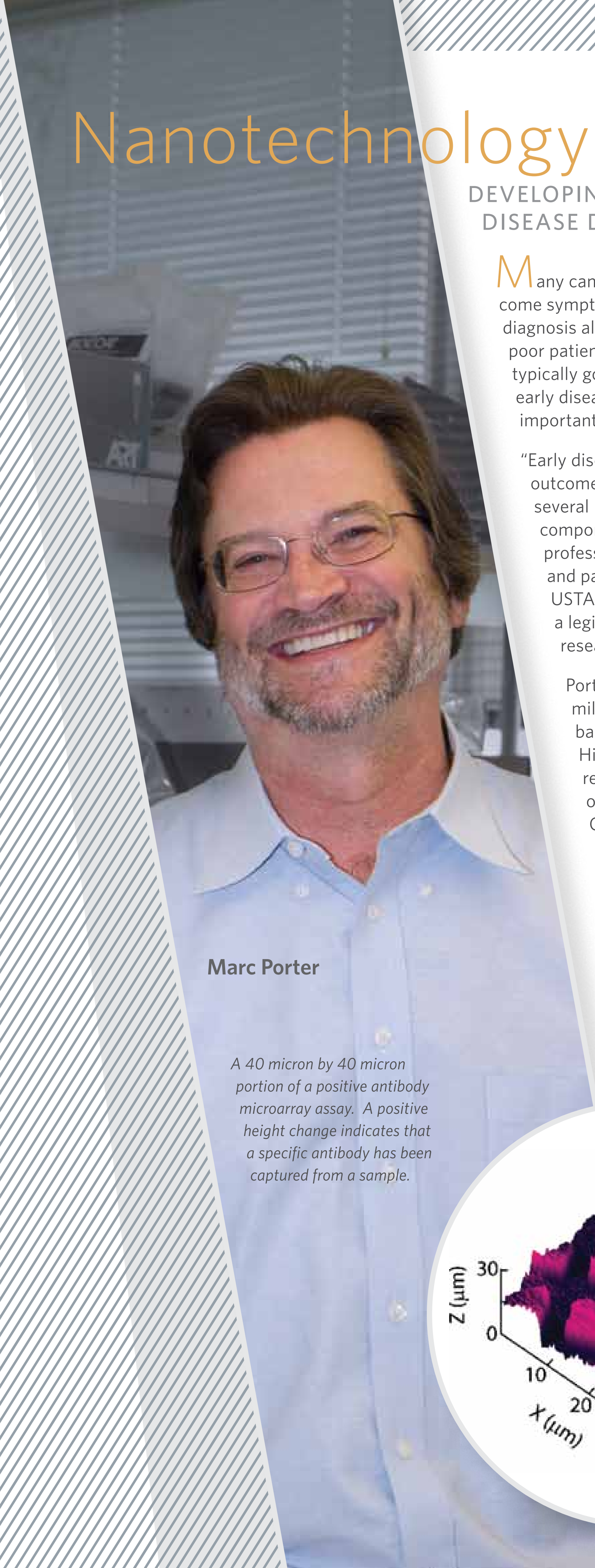
Once an ablation is performed, the patient is immediately taken back into the MRI scanner to see whether all of the problem spots were treated. The success rate is currently in the range of only 60 to 80 percent. "Ablation causes the tissue to blister, so it is difficult to see exactly what's happened until the heart heals," he says. "We have to wait for about three months for another MRI to see whether any spots were missed."

To solve this problem, the CARMA team is integrating real-time MRI with ablation therapy. Last year the team opened the first integrated electrophysiology MRI laboratory in North America with a high-tech scanner that provides high-resolution images of the heart. The lab also includes fluoroscopy, computed tomography and intracardiac echo. Patients move along a track in the floor between fluoroscopy and MRI areas (the two technologies cannot yet exist in the same scanner), and images from both systems will be immediately fused and updated in real time as the patient undergoes ablation.

As part of his research into the electrophysiology of the heart, MacLeod and his group are seeking to develop quantification software that shows whether the research can be applied universally. "We are working nationally with 12 centers that send us their images so we can see whether our algorithms work on a broad variety of images, not just our patients," MacLeod says. CARMA is also developing software that will link patient records with images, so that patients have access to their images in the doctor's office. Further, CARMA researchers are working with Chuck Grissom in the chemistry department at the U to develop better biomarkers for atrial fibrillation.

Nanotechnology in Medicine

DEVELOPING BIOSENSORS FOR EARLY DISEASE DETECTION



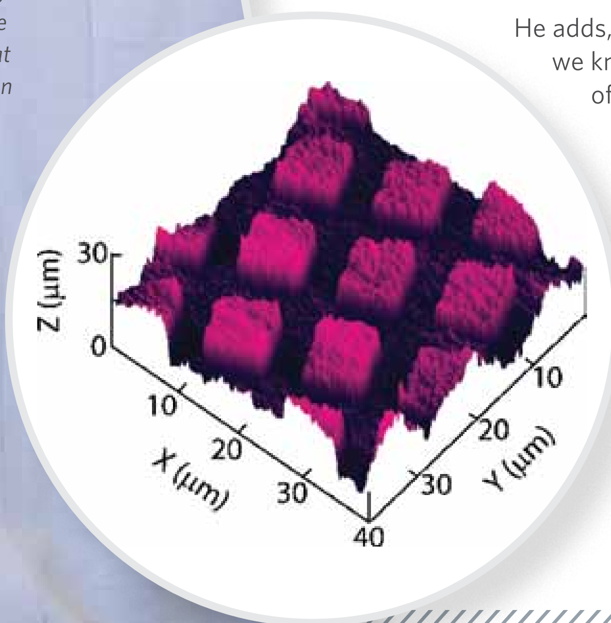
Marc Porter

Many cancers and other diseases are diagnosed when they become symptomatic or are detected through screening. Symptomatic diagnosis also carries the probability of advanced malignancy and poor patient prognosis. However, successful patient outcomes typically go hand-in-hand with early detection, and it appears that early disease detection can be enhanced by routinely screening for important disease biomarkers.

"Early disease diagnosis is paramount for successful patient outcomes, and by developing instruments that can screen for several biomarkers at once we feel we're preparing a necessary component to drive this paradigm," says Marc Porter, USTAR professor of chemical engineering, chemistry, bioengineering and pathology, and director of the Nano Institute of Utah. USTAR (Utah Science, Technology and Research Initiative) is a legislative initiative designed to strengthen technological research and stimulate economic development in Utah.

Porter and his collaborators have been awarded a multi-million dollar federal grant to develop a nanotechnology-based platform for the early detection of pancreatic cancer. His collaborators include professor Sean Mulvihill and research assistant professor Matt Firpo from the School of Medicine and senior research scientist Michael Granger from the Nano Institute.

Pancreatic cancer is particularly deadly—it is the fourth leading cause of death from cancer in the United States. Less than 5 percent of patients live longer than five years after diagnosis. "Pancreatic cancer is usually asymptomatic in the initial stages of progression," Porter says. "An individual may feel like he has a cold or some pain in his lower back, but he may attribute these symptoms to something other than cancer. By the time the cancer is diagnosed, it is often too late for surgery."



A 40 micron by 40 micron portion of a positive antibody microarray assay. A positive height change indicates that a specific antibody has been captured from a sample.

He adds, "But on the other hand, we know that early diagnosis of pancreatic cancer can save lives. A real-life success is [Supreme Court Justice] Ruth Bader Ginsburg whose asymptomatic pancreatic cancer was found at an early stage through a routine CAT scan. Due to the early resection of the tumor, she is still in remission."

Microarray Biosensors

Porter and his associates are seeking to advance the early detection of cancers and other diseases through the development of nanotechnology "biosensors"—devices that detect biological materials at ultra-low levels. "Nano" refers to the tiny, molecular scale of the technology. By screening for combinations of biomarkers that are indicative of specific diseases, they hope to bring early disease detection closer to reality.

Porter is developing microarray biosensors that consist of one or more antibodies affixed to glass slides. Each antibody corresponds to a particular biomarker. When the array is exposed to a blood or urine sample, antigens bind to complementary antibodies and indicate the possibility of a particular disease.

"The eventual deployment of the technology—for instance, in your primary caregiver's office—would mean that test results are logged in a secure databank, so that the caregiver could monitor biomarker fluctuations over time to see how they are doing," says Porter, who would like to make the tests accessible and affordable to patients. "What if we could make these tests readily available, much like checking your blood pressure at your family doctor's office or a pharmacy?"

One of the challenges to this technology, however, is reliability. Researchers dispute how much of the data obtained from this type of biosensor is accurate with some arguing that only 30 to 40 percent of the information can reliably be used.

"We need to find the right biomarkers that are clear signatures of a particular disease, so that we can improve the accuracy in early detection," Porter says. "We also hope to realize breakthroughs in the detection of tuberculosis and invasive fungal infections and to enable the development of new and improved vaccines for these and other diseases."

Porter and his associates are also working on the next generation of diagnostic biosensors using gold nanoparticles, which are coated with antibodies so that specific biomarkers will bind to them. Gold nanoparticles can dramatically affect the way light is scattered and enhance optical signals. "If we can detect a signal from one nanoparticle, then we can detect ultra-low biomarker levels and increase the probability of earlier disease detection," he says.

Magnetoresistive Sensors

Aside from optical disease marker detection, another area of Porter's research, magnetoresistive (MR) sensors, centers on developing disease detection methods using the same magnetic principles common to a computer hard drive. He and his team have successfully created a sensitive prototype device that could potentially test for hundreds of diseases simultaneously by acting like a credit card swipe machine to scan a card loaded with blood, saliva or urine samples.

The prototype card swipe device consists of an MR "read head" and sample stick. When the device is developed commercially, the MR sensor device could look like a credit card reader or floppy disk drive reader. "Think how fast your PC reads data on a hard drive, and imagine using the same technology to monitor your health," he says. "Unlike lab tests today, results could be available in minutes, not days or weeks."

Magnetoresistance is the change in a material's resistance to electrical current in the presence of an external magnetic field. That change is usually less than 1 percent. However, Porter uses thin magnetic materials fabricated as multilayers to display a change in resistance of as much as 20 percent at room temperature. This method is very sensitive, detecting as few as 800 microscopic particles on an address. With further development, Porter believes they can achieve single-particle detection to test blood or other samples for viruses that can cause disease in minute concentrations.

WATER QUALITY IN ORBIT

USTAR professor Marc Porter and his team have developed a two-minute water quality monitoring method for the International Space Station to ensure drinking water is adequately disinfected for use in space. "Now they bring water back on the space shuttle and analyze it on the ground. The problem is there is a big delay. You'd like to be able to maintain disinfectant levels in real time with an onboard monitor," says Porter.

Water for astronauts is either carried into orbit or reclaimed and purified from astronaut waste. Disinfectants or biocides are added during flight. Until now, actual levels of the biocides in drinking water have not been tested on-station.

The water quality monitoring method involves sampling space station or space shuttle galley water, forcing the water through a chemical-impregnated membrane, and then reading the color of the membrane with a commercially available color sensor normally used to measure the color and glossiness of automobile paint.

Using the sensor, astronauts can determine whether their drinking water contains enough iodine (used on U.S. spacecraft) or silver (used by the Russians) to kill any microbes. "Our focus was to develop a small, simple, low-cost testing system that uses a handheld device, doesn't consume materials or generate waste, takes minimal astronaut time, is safe, and works in microgravity," says Porter.

The project is funded by the National Aeronautics and Space Administration, USTAR, Arizona State and Iowa State. The project team also includes Wyle Laboratories. After months of testing, the device is now installed permanently in the International Space Station.

Composites in Cars

MAKING VEHICLES LIGHTER, SAFER AND MORE FUEL-EFFICIENT

LEFT: *Dan Adams holds two carbon/epoxy tube specimens used to assess composite crashworthiness. The one on the right is before testing. On the left is after crush testing, showing the high degree of fragmentation and thus high-energy absorption.*

BELOW: *A carbon/epoxy composite panel that has been subjected to impact damage.*

Composite materials may someday have big advantages over steel in automobile manufacturing. Composites are being considered to make lighter, safer and more fuel-efficient vehicles. A composite is composed of a high-performance fiber (such as carbon or glass) in a matrix material (epoxy polymer) that when combined provides enhanced properties compared with the individual materials by themselves.

Carbon-fiber composites weigh about one-fifth as much as steel, but are as good or better in terms of stiffness and strength. They also do not rust or corrode like steel or aluminum, and they could significantly increase vehicle fuel economy by reducing vehicle weight by as much as 60 percent, according to the Oak Ridge National Laboratory (ORNL).

"With composite materials, we get high strength-to-weight and stiffness-to-weight ratios, as well as excellent energy-absorbing capability per mass," says Dan Adams, professor of mechanical engineering at the University of Utah who is collaborating with ORNL on the development of test methods for automotive composites. "Steel is strong and inexpensive, which is why it's the material of choice today. But composites can be designed to be strong and light to provide better safety and fuel efficiency."

Adams says that the strength and stiffness factors are why composites are currently used in aerospace applications, which also require a material that is extremely light. And compared to single-layered steel in cars, multiple-layer composite laminates can be designed to absorb more energy in a crash. "However, the use of these materials in the automotive industry has been very limited partly because of the costs associated with the materials and manufacturing," he says. Adams and his associates are addressing these issues, along with design safety, as they develop test methods and assess candidate composites for automotive applications.

Engineering for Crashworthiness

Adams' research focuses on the mechanics of sandwich composites, which are a special class of composite structures made by attaching two thin composite facesheets to a thick, low-density core of balsa wood or foam. Sandwich composites are of interest for automotive floor and roof applications.

Nearly two decades ago, Adams began studying how to make sandwich composites more "damage tolerant," where the structure can still meet its load requirements after it has sustained some type of initial damage. "Investigating the mechanics of damage tolerance required understanding the failure progression (the types and locations of failure)," says Adams. "It required that we look carefully at what was happening after there was already an initial failure."

Eventually Adams was selected to lead the U.S. Automotive Composite Consortium's first research investigation into the "crashworthiness" (the ability to protect occupants in a crash) of sandwich composites. "For me, crashworthiness was a natural extension of damage tolerance," he says. "We just kept applying load to an already failed sandwich panel and examined how it crushed. Conventional sandwich composites would quickly come apart with the facesheets debonding and the remaining core buckling or being pushed aside with little energy being absorbed."

With the proper design, Adams says that composites can meet or even exceed safety requirements in a crash because they can be designed to absorb significantly more energy than traditional metallic metals when crushed. "Metals absorb energy in a crush by yielding, whereas composites typically crush in a more brittle manner," he says. "Energy is absorbed through repeated failure of the material. The ideal case would be the composite structure being broken into tiny pieces where the crush occurs, but everything else is intact. The materials have to be designed to fail in a controlled manner."

Already the initial sandwich design Adams and his students worked on a few years ago has made its way into the Chevrolet Corvette. Adams is continuing to develop test methods for assessing crashworthiness of composites with organizations such as ORNL and Engenuity Limited, an engineering consulting company based in the U.K. "No accepted test methods exist and we need them to screen materials for crashworthiness as well as to provide the required experimental results for validating computational modeling methods," he says.

In 2010, Adams was selected by the U.S. Department of Transportation to write a 100-page white paper on the current status and research needs for plastic and composite intensive vehicles. The government is hoping to facilitate their safe deployment by 2020. "It was really exciting to have the opportunity to identify what needs to be done in the next ten years to make automotive composites a reality," Adams says.

LOWERING COSTS FOR AUTOMOTIVE COMPOSITES

Affordability is an important issue in vehicle manufacturing, which includes factoring in the costs associated with a car's complete life-cycle—including manufacturing, operating and disposal costs. "The issue with today's composites is that they have been developed for aerospace applications where cost is not as critical," says Dan Adams, professor of mechanical engineering.

Pound for pound, material costs of carbon fiber composites are at least 20 times as much as steel, and the automotive industry is unlikely to use them until the price of carbon fiber drops significantly. The processing of carbon fibers is too expensive and slow, says Adams. The raw carbon material is converted to carbon fibers using thermal pyrolysis, a slow, energy-consuming process that is combined with stressing to achieve a high percentage of carbon with the proper fiber tension. The raw material, the energy needed to heat it to make fibers, and the required equipment all contribute to the high cost. As a result, carbon-fiber composites cannot yet compete economically with steel in the auto industry.

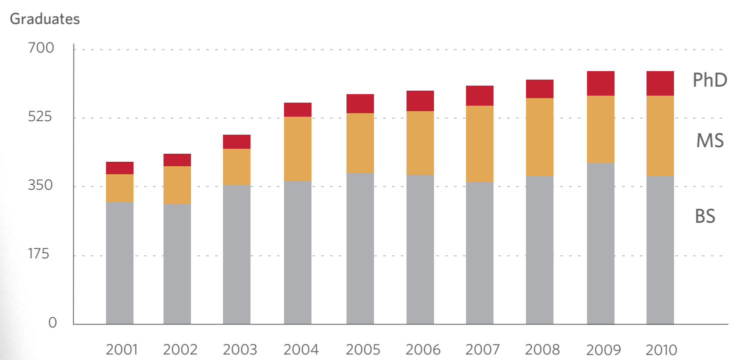
"The development of low-cost carbon fiber is an active research area with great promise," says Adams. "Also the development of low-cost manufacturing methods for automotive composites is receiving a lot of attention. There are less expensive ways of manufacturing composite automobile parts that also reduce the number of joints and fasteners. We could make these materials very affordable."

Facts & Financials

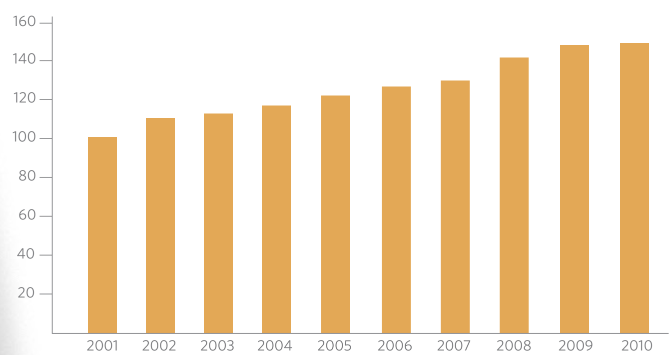
- The College of Engineering is among the top 50 engineering schools in the nation in student enrollment: 49th out of 360 schools at the undergraduate level, and 48th out of 261 schools at the graduate level.
- The College of Engineering is 43rd in the nation out of 197 schools in the number of engineering doctoral degrees awarded.
- Of 337 schools, the College of Engineering is 37th in the nation in the number of tenure-track faculty.

SOURCE: The American Society for Engineering Education—2010 edition of the Profiles of Engineering and Engineering Technology Colleges

DEGREES AWARDED: 2001–2010



TENURE-TRACK FACULTY GROWTH: 2001–2010



For 2010, the College of Engineering is again ranked among the top 100 Engineering/Technology and Computer Sciences programs by the *Academic Ranking of World Universities* compiled by Shanghai Jiao Tong University, the most prominent world university ranking, based on academic and research performance, international recognition, highly-cited research, articles in the Science Citation Index and Social Science Citation Index, articles published in top journals, and engineering research expenditures. The University of Utah as a whole is ranked 82nd among the world's top 500 universities.

TECHNOLOGY COMMERCIALIZATION: 2006–2010

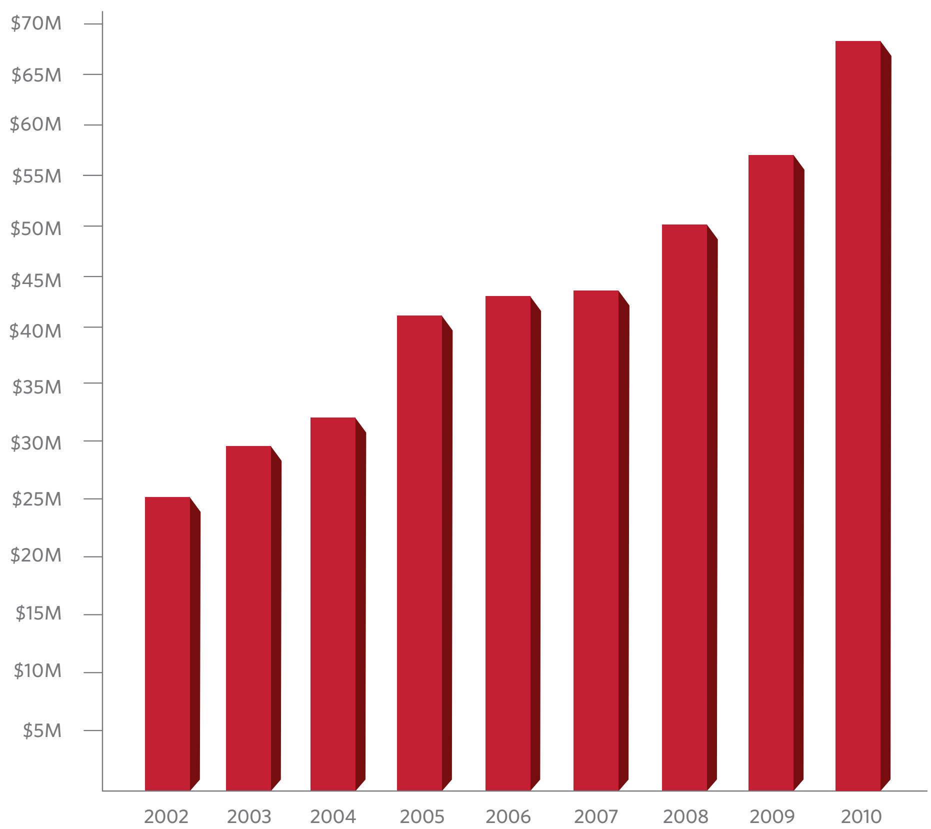
The University of Utah surpassed MIT to become the nation's **No. 1** research institution at starting companies based on university technology, according to the Association of University Technology Managers, which ranks public and private research institutions throughout the country. The U of U has achieved the top ranking with a fraction of the research budget of other major universities.

The U of U launched 20 new companies from technologies developed at the University in 2006, 17 in 2007, 23 in 2008, 23 in 2009, and 19 in 2010. The College of Engineering is responsible for 42 of these spin-off companies.

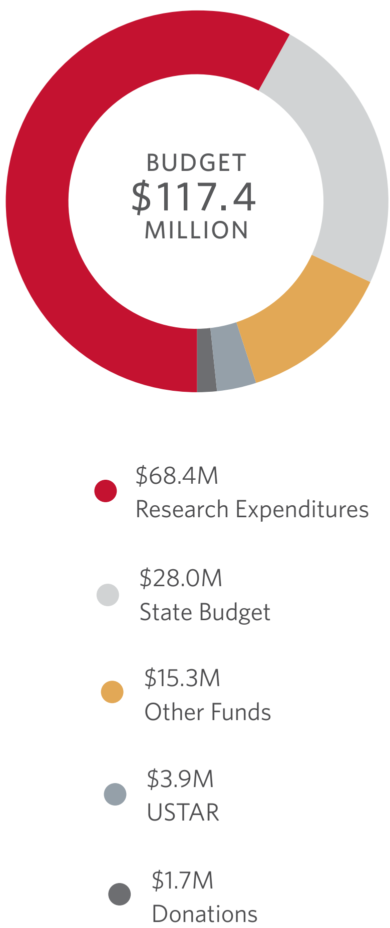
The University of Utah's intellectual property is managed by its Technology Commercialization Office (TCO). Since 2005, TCO has focused on economic development in the state of Utah. TCO has set up a satellite office in the College of Engineering to direct the college's extensive technology commercialization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

RESEARCH EXPENDITURES: 2002–2010

With **$68.4 million** annually in external research funding, the College of Engineering is ranked 36th in the nation out of 203 schools in research expenditures. The College of Engineering is a vital component of the University of Utah's growing research enterprise.



BUDGET: 2009–2010



Distinguished Service Award

David S. Layton, president and CEO of the Layton Companies and a member of the College of Engineering's National Advisory Council, has received the College's Distinguished Service Award for his outstanding service to the advancement of engineering education. His personal engagement and leadership, along with the exceptional Layton team, are helping to transform the U's engineering academic and research environments.

Layton Construction Company was founded in 1953 by Layton's father and University of Utah alumnus, the late Alan W. Layton. The Layton Companies, which has done extensive work on the U campus, has recently completed renovations to the Floyd and Jeri Meldrum Civil Engineering Building and is currently building the James L. Sorenson Molecular Biotechnology Building—A USTAR Innovation Center.

In fall 2011, the college will also award a scholarship in Layton's name to a student who has demonstrated distinguished service.

ENAC

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Managing Principal Mid-America
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Van Boerum & Frank, Associates, Inc,

Robert B. Wiggins
Retired–President
Quartzdyne, Inc.

Kim Worsencroft
Entrepreneur

College of Engineering Disciplines

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.

A wall display in the Warnock Engineering Building represents the College of Engineering's seven academic units.

Bioengineering // Chemical Engineering // Civil & Environmental Engineering // Electrical & Computer Engineering // Materials Science & Engineering // Mechanical Engineering // School of Computing

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
- Nano Institute

RESEARCH CENTERS

- Utah Nuclear Engineering Program (UNEP)
- 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

Living in Utah

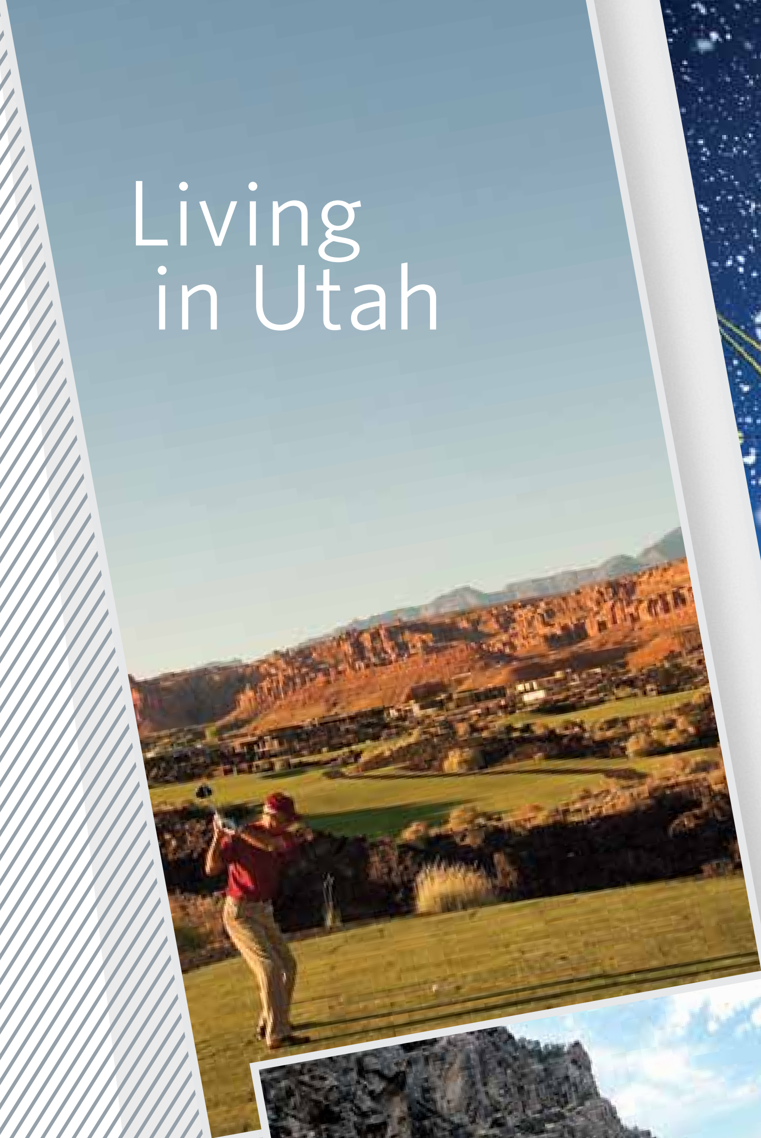

PHOTO CREDIT: State of Utah

Utah: Leading the Way

Utah's Economy

In the last decade, the College of Engineering has focused on a strategy of growth with quality—a commitment that has helped us graduate more highly qualified engineering and computer science leaders who are contributing to the economy in Utah. The following economic statistics and rankings are just some of Utah's recent accomplishments:

"The Best State for Business and Careers" — Forbes Magazine

"Number 1 for overall future economic outlook" — Rich States, Poor States: ALEC-Laffer State Economic Competitiveness Index

"Best managed state in the nation"— The Pew Center on the States

"Most dynamic economy" — Kauffman State New Economy Index

According to 2010 rankings released by the Milken institute, a California-based think tank that evaluates the 50 states' technology commercialization endeavors:

- Utah is number 5 overall in the nation for its technology and science capabilities and their conversion into companies and high-paying jobs
- As part of this ranking, Utah is number 1 in the nation for "Technology Concentration and Dynamism," number 5 for "Risk Capital and Entrepreneurial Infrastructure" and number 8 for "Human Capital Investment"

A 2011 CNBC special report lists Utah as the 8th best state in the country for business. The study reviewed all 50 states in 43 categories of competitiveness with input from business groups. The 10 categories ranked in the study include: cost of doing business, workforce, quality of life, economy, transportation and infrastructure, technology and innovation, education, business friendliness, access to capital and cost of living.

USTAR

The Utah Science Technology and Research initiative (USTAR), a long-term, state-funded effort to strengthen technological research and stimulate economic development in Utah, is instrumental in helping Utah to achieve such rankings. This measure provided funding for strategic investments at the University of Utah to recruit world-class researchers and build state-of-the-art interdisciplinary research and development facilities and to form first-rate science, innovation, and commercialization teams across Utah.

As of June 2010:

- USTAR had recruited more than two dozen top researchers to the U of U
- USTAR researchers had created six new companies
- USTAR innovators have filed 87 invention disclosures
- USTAR researchers have brought more than $44 million of new out-of-state research funding to Utah
- Including all research grants committed for future years (through FY2014), USTAR researchers account for $103 million in new funding—199% leverage of Utah's research investment ($52 million) to date
- USTAR has created an estimated 1,984 jobsin addition to 800 construction jobs on USTAR building projects
- The U of U's Technology Commercialization Office opened a new incubator and prototyping facility in September 2010 to boost the number of start-up opportunities

Questions or comments?
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THE UNIVERSITY OF UTAH

College of Engineering
2011 RESEARCH REPORT

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