POWER GENERATION

Harvesting a Bountiful Energy Future

A dozen emerging energy technologies provide power from sources you might never expect.

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VERY QUIET ROOM

The Georgia Tech Research Institute (GTRI) operates an indoor compact range used for radar cross section measurements and antenna testing. The facility is shielded against electromagnetic interference and used for both internal research and collaborations with industry. The range is 18 feet high, 24 feet wide, and 60 feet long. It can test at frequencies ranging from 2 gigahertz to 100 gigahertz, and that range can be extended down to 200 megahertz to accommodate UHF antenna testing. Shown under test is a Skywalker X8 airframe that is being used as a test bed for swarming UAV research. The aircraft is undergoing antenna pattern characterization as part of an investigation into inter-aircraft communications. Photo by Rob Felt.
Georgia Tech is a partner in the scientific collaboration that operates the Laser Interferometer Gravitational-wave Observatory (LIGO) and operates a mock-up LIGO control room on campus. In February, the LIGO Scientific Collaboration announced that it had confirmed the detection of gravitational waves at both LIGO detectors, located in Livingston, Louisiana, and Hanford, Washington. The LIGO observatories are funded by the National Science Foundation, and were conceived, built, and are operated by Caltech and MIT. Photo by Rob Felt.
The Georgia Tech Research Institute (GTRI) operates a far-field antenna test range at its facility in Cobb County, Georgia. The range consists of two multistory signal towers—source and receiver—located 1,300 feet apart. The facility features a heavy-duty, three-axis positioner capable of handling antennas up to 30 feet in diameter and weighing up to 30,000 pounds. The range’s massive towers ensure extreme mechanical precision and stability. Photos by Rob Felt.

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GEORGIA TECH DEVELOPS NEW ENERGY, THERMAL, AND AUTONOMOUS VEHICLE TECHNOLOGIES

Georgia Tech is developing the next generation of energy technologies that could help power everything from the tiniest of wireless sensors to ultra-efficient homes and businesses. Harvesting energy from mechanical motion and converting heat from the environment are among the strategies, but researchers are also collecting energy from nuclear waste and gathering electricity from radio and television broadcasts. Other research projects are developing smaller heat pumps and better supercapacitors — and examining supercritical carbon dioxide to replace steam in power plants.

Putting electricity into computer devices generates heat that must be removed. Georgia Tech researchers are working on new approaches for that, from developing more thermally efficient integrated circuits and water cooled chips to optimizing the design of data centers. Their work could result in more powerful and efficient mobile devices and lower energy costs for the data centers that make cloud computing possible.

Also in this issue, you will learn about the many challenges that are slowing the introduction of autonomous vehicles. Operating a driverless car on a smooth highway is one thing; dealing with unpredictable terrain, vehicles that still have drivers, and environment are among the strategies, but researchers are also collecting energy from nuclear waste and gathering electricity from radio and television broadcasts. Other research projects are developing smaller heat pumps and better supercapacitors — and examining supercritical carbon dioxide to replace steam in power plants.

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Also in this issue, you will learn about the many challenges that are slowing the introduction of autonomous vehicles. Operating a driverless car on a smooth highway is one thing; dealing with unpredictable terrain, vehicles that still have drivers, and energy technologies, and thermal control for electronic devices. As always, I welcome your feedback. Enjoy the magazine!

Steve Cross
Executive Vice President for Research
April 2016
LONG IN THE TEETH

When a Lake Malawi cichlid loses a tooth, now one drop neatly into place as a replacement. Why can’t humans similarly regenerate lost teeth? Working with hundreds of these colorful fish, researchers are beginning to understand how the animals maintain their teeth throughout their adult lives. By studying how structures in embryonic fish differentiate into either teeth or taste buds, the researchers hope to one day be able to turn on the tooth regeneration mechanism in humans — who, like other mammals, get only two sets of teeth.

Differentiation in mice, shows that the structures like other mammals, get only two sets of teeth.

To understand more about the pathways that lead to the growth and development of teeth, Streelman has dealt with dental issues at one time or another. "In hydrogel-coated tubes, rather than moving according to conventional expectations, water-based liquids slip to a new location in the tube, get stuck, then slip again — and the process repeats over and over again," explained Andrei Fedorov, a professor in Georgia Tech’s School of Physics. "Instead of filling the tube at a rate that slows with time, the water propagates at a nearly constant speed into the hydrogel-coated capillary."

When the opening of an ordinary thin glass tube is exposed to a droplet of water, the liquid begins to flow into the tube, pulled by a combination of surface tension and adhesion between the liquid and the walls of the tube. Leading the way is a meniscus, a curved surface of the liquid at the leading edge of the water column. An ordinary borosilicate glass tube fills by capillary action at a nearly constant speed into the hydrogel-coated capillary.
COMING SOON: CLIMATE CHANGE IMPACTS

For the 70,000 residents of the Marshall Islands, global climate change isn’t a theoretical concern with far-off consequences. The island nation is no more than 6 feet above the Pacific Ocean, and because sea levels are already rising, the nation’s leaders have made plans to move the entire population to higher ground in the Fiji Islands.

Some impacts of global climate change will appear much sooner than others with only moderate increases in global temperature. For example, while rising sea level may one day threaten the subway lines of New York City, it will have effects much sooner in other parts of the world. Rising temperatures may one day make parts of the globe uninhabitable, but smaller temperature changes have already begun to decimate Pacific coral reefs.

Only immediate and aggressive effort to mitigate the effects of climate change can head off these accelerating near-term impacts, argues a commentary paper published in the journal Nature Geoscience. As more impacts occur, the incentives for addressing the causes will themselves change, the paper’s authors warn.

“Our argument is that if you want to do something, you’d better do something now because over time, you are going to lose the ability to have an impact,” said Juan Moreno-Cruz, an assistant professor in Georgia Tech’s School of Economics and one of the paper’s co-authors. “If two delay action on climate change, the likelihood of doing something will be reduced because the damages will be accelerating. The incentives to address it are going to disappear as more damage occurs.”

Climate change impacts are often assumed to increase steadily with global temperature increases, but that’s not true for all impacts. The scaling of many impacts with temperature may have a nonlinear sigmoidal pattern, with a dramatic initial impact followed by a leveling off as warming continues, said the paper’s authors at Georgia Tech, the Carnegie Institution Impact Research. — John Toon

The Virtual Electronic Combat Training System (VECTS) provides U.S. aircraft with full multiscope functionality—the ability for two or more aircraft to train together realistically regardless of their physical locations. — Dick Robinson

HUMAN FACTORS

Melanie Quiver, a Ph.D. student in Georgia Tech’s School of Biology, studies human population genetics and evolutionary genomics. Quiver’s research focuses on the genetic risk of alcoholism in modern populations.

WHERE ARE YOU FROM?

I’m from a small town called Kayenta, on the Navajo reservation in northern Arizona. I am of the Ta’u People clan, born for the Ian Felipe Pohoo Fox clan. My maternal grandfather was of the Deer Springs People clan and my paternal grandfather was of the Bitter Water People clan.

WHAT BROUGHT YOU TO GEORGIA TECH?

I attended Northern Arizona University for my undergrad, where I also worked at the Center for Microbial Genomics and Genomics. I graduated with a B.S. in biology in 2014. Graduating school was never part of the plan, but my mentor, Jeff Foster, encouraged me to apply to the FOCUS program. The three-day event at Georgia Tech is designed to raise awareness of graduate education among underrepresented students. I attended the program in January 2014 and that experience is the second I remember who I’m doing it for: my community. — Melanie Quiver

IT SEEMS AS THOUGH YOUR INTEREST AND PASSION IN BIOLOGY IS INTERWOVEN INTO YOUR BACKGROUND. It’s primarily because of where I grew up. The Navajo reservation is prevalent with addiction in various forms, such as alcohol, drugs, and gambling. This has affected the mindset of our youth. We have the lowest (college) enrollment numbers in history, and I think that introduces an opportunity for improvement. It’s my hope that I contribute to that improvement and inspire indigenous youth to go after their passion as well. Graduate school can be challenging, but that doubt disappears the second I remember who I’m doing it for: my community. — Laura Diamond
AN ‘INVASIVENESS INDEX’ FOR BREAST CANCER

Biomedical engineers have demonstrated a proof-of-principle technique that could give women and their oncologists more personalized information to help them choose options for treating breast cancer.

Thanks to diagnostic tests, clinicians and patients can already know the type of breast cancer they’re up against, but one big question remains: How likely is it that the cancer will invade other parts of the body? Answering that question could help guide treatment selection: from aggressive and difficult therapies, such as chemotherapy, to more conservative ones.

By studying chemical signals from specific cells that are involved in helping cancer invade other tissues in each woman’s body, researchers have developed a predictive model that could provide an invasiveness index for each patient.

“We want women to have more information to make a personal decision beyond the averages calculated for an entire population,” said Manu Platt, an associate professor in Georgia Tech’s School of Chemistry and Biochemistry and one of the paper’s senior authors.

“We needed a tool that could discriminate between locations to provide more than a whole readout of oxidation,” said Melissa Kemp, an associate professor in the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University. “With very specific spatial information, we will be better informed about how cellular processes or antioxidant therapies are going to operate.”

Other researchers had already created variants of the commercially available HyPer reporter protein, which allows its fluorescence properties in the presence of hydrogen peroxide. Here, the researchers added a tubulin-binding protein known as Tau that anchors the protein to microtubule structures that crisscross cells like railroad tracks. Fluorescence microscopy then allows them to observe the real-time change as oxidation occurs.

This super-resolution fluorescence microscopy image of HyPer-Tau shows the microtubular structure of a human colon cancer cell. The image was made using the new super-resolution microscopy in the Georgia Tech Institute for Biotechnology & Bioscience (IBB).

ANALYTICAL CHEMISTRY OFFERS EARLY WARNING

Metabolic Profiles Distinguish Early-Stage Ovarian Cancer

Studying blood serum compounds has led scientists to a set of biomarkers that may enable development of a highly accurate screening test for early-stage ovarian cancer. By using advanced liquid chromatography and mass spectrometry techniques coupled with machine-learning computer algorithms, researchers have identified 16 metabolites that provided unprecedented accuracy in distinguishing 46 women with early-stage ovarian cancer from a control group of 40 women who did not have the disease.

While the set of biomarkers is the most accurate reported thus far for early-stage ovarian cancer, more extensive testing is needed to determine if the diagnostic accuracy will be maintained across a larger group of women.

“This work provides a proof of concept that using an integrated approach combining analytical chemistry and learning algorithms may be a way to identify optimal diagnostic features,” said John McDonald, a professor in Georgia Tech’s School of Biology and director of its Integrated Cancer Research Center. “We think our results show great promise and we plan to further validate our findings across much larger samples.”

Ovarian cancer has been difficult to treat because it typically is not diagnosed until after it has spread to other areas of the body. Researchers have been seeking a routine screening test that could diagnose the disease while it is still confined to the ovaries.

Working with cancer treatment centers in the US and Canada, the researchers obtained blood samples from women with stage one and stage two ovarian cancers. They separated out the serum, which contains proteins and metabolites — molecules produced by enzymatic reactions in the body. The serum samples were analyzed by ultra-performance liquid chromatography-mass spectrometry (UPLC-MS), two instruments joined together to better separate samples into their individual components. The researchers decided to look only at the metabolites.

“People have been looking at proteins for diagnosis of ovarian cancer for a couple of decades, and the results have not been very impressive,” said Facundo Fernández, the professor in Georgia Tech’s School of Chemistry and Biochemistry who led the analytical chemistry part of the research. “We decided to look in a different place for molecules that could potentially provide diagnostic capabilities.”

The research was reported in the journal Scientific Reports.

— JOHN TOON
MICROELECTRONICS GROWS INTO NANOTECHNOLOGY

In 1983, largely on the strength of Georgia Tech, Georgia became a finalist to headquarter the Microelectronics and Computer Technology Corporation (MCC), a pioneering consortium of technology companies. Though Georgia lost out to Austin, Texas, the economic potential of microelectronics was a lesson learned by the state’s economic development community.

In the Summer 1986 issue of Research Horizons, plans were announced for a new Microelectronics Research Center, which was envisioned as a $10 million facility funded by the Georgia General Assembly to boost microelectronics research in Georgia. The facility, which became the Joseph M. Pettit Microelectronics Research Center, replaced a smaller facility in the basement of Technology Building. IEN operates approximately 80,000 square feet of clean room, research, fabrication, and characterization facilities that, in addition to being used by Georgia Tech faculty members, are shared by users from more than 70 academic institutions, companies, and government agencies engaged in microelectronics and nanotechnology research. In total, more than 150 users benefit from the IEN fabrication and characterization facilities on an annual basis.

IEN is a member of the NSF’s National Nanotechnology Coordinated Infrastructure (NNCI) and has shared user equipment valued at nearly $250 million. The equipment is used for a broad range of technologies, including nanomaterials and structure, compound and multilayer semiconductors, processing and device fabrication, optoelectronic and photonic devices; micro-electromechanical systems (MEMS) and nano-electromechanical systems (NEMS) high-speed electronic and wireless systems; interconnect technology; system integration and packaging; and energy harvesting and storage.

“Electronics and nanotechnology are essential to all facets of today’s economy, from traditional electronics to new areas in health care and renewable energy,” said Oliver Brand, executive director of IEN. “The original vision for microelectronics has expanded into so many other areas, and just recently to include the manufacturing of therapeutic vials, an innovation that could not have been envisioned with the concept of a shared user facility back in the early 1980s.” — JOHN TOON

DEAD IN THE WATER

El Niño conditions in the Pacific Ocean have seriously damaged coral reefs, including those on Christmas Island, which may be the epicenter for what could be a global coral bleaching event. Georgia Tech researchers who visited the island reported that 50 to 90 percent of corals they saw were bleached and as many as 30 percent were dead at some sites.

“This El Niño event is driving one of the three largest global-scale bleaching events on record,” said Kim Cobb, a professor in Georgia Tech’s School of Earth and Atmospheric Sciences who has studied long-term El Niño conditions. “Ocean temperatures exceeded the threshold for healthy corals back in the summer.”

Bleaching is an outward sign of stress in the coral, which causes the symbiotic algae that normally help provide them with energy to sustain their metabolism. The loss of these algae turns the coral colonies white and makes them more vulnerable to disease and death. Bleached corals can recover of water temperatures return to normal.

Cobb and other researchers measured water temperatures of 33 degrees Celsius (91 degrees Fahrenheit), well above normal water temperatures of 27 degrees Celsius (81 degrees Fahrenheit). “There’s an astounding amount of warming at this time,” said Cobb.

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Antibiotic resistance in bacteria is among the most critical public health threats today. As more existing antibiotics lose their ability to wipe out infections, research is under way to develop new drugs that can attack the bugs in different ways.

Key to that effort is understanding how bacteria organize and operate compiles that can be developed to attack the microorganisms at their weakest points. For example, Georgia Tech researchers are modeling gram-negative bacteria such as E. coli, N. gonorrhoeae, and Salmonella to find gaps in their cellular defenses—specifically, their outer cell membranes. Having detailed models of these structures can help experimentalists understand their research is showing and point to new areas of investigation.

“You must be able to imagine how models of those structures can help experimentalists ask new questions,” said John Toon, a professor in Georgia Tech’s School of Physics. “It’s really important that we have very accurate models to understand how different bacteria interact with the immune system and with potential drugs in diverse ways.”

The bacteria that Gumbart studies are unusual in that they have two outer membranes, one on each side of the cell wall. These membranes are very different from those of other cells, and they have special features that may provide avenues for pharmacological attack.

But even the best experiments can’t show all of the factors involved in the membranes’ functions, which is why models can be useful. The models, which are run on high-performance computers both locally and at national supercomputing centers such as the one at Oak Ridge National Laboratory, combine experimental data with basic principles and computational techniques for performing simulations, we can measure things that are essentially impossible to ask in real cells.

And so, the researchers have shown that in crowded cells tend to linger near cell walls, while confinement in the viscous liquid inside cells causes particles to move about more slowly than they would in an infinite volume. “This is a very heterogeneous and dense environment with much more than 40% of the volume occupied,” Gumbart said.

While the simulations didn’t include the DNA strands or metabolite particles also found in cells, they did include up to a half million objects. Using physics principles, Skolnick and Chow considered what the particles would do in a cell just a few micrometers in diameter.

“From the results of the computer simulations, we can measure things that we think might be interesting, such as the diffusion rates near the walls and away from the walls,” Chow said.

The research is a collaboration between Edmond Chow, an associate professor in Georgia Tech School of Computational Science and Engineering, and Jeffrey Skolnick, a professor in Georgia Tech’s School of Biology. Their goal is to develop and study models for simulating the motions of molecules inside a cell, and also to develop advanced algorithms and computational techniques for performing large-scale simulations.

Skolnick compared the interior of a living cell to a large New Year’s Eve party. “It’s kind of like a crowded party that has big people and little people, snakes — DNA strands — running around, some really large molecules, and some very small molecules,” he said.

“Triboelectric nanogenerators are a new energy technology that has shown phenomenal potential,” said Zhong Lin Wang, a Regents Professor in Georgia Tech’s School of Materials Science and Engineering. “Here, we have proposed standards by which the performance of these devices can be quantified and compared. These standards will be useful for academic researchers developing the devices and for future industrial applications of the nanogenerators.”

“Triboelectric nanogenerators use a combination of the triboelectric effect and electrostatic induction to generate small amounts of electrical power from mechanical motions such as rotation, sliding, or vibration. The triboelectric effect takes advantage of the fact that certain materials become electrically charged after they come into moving contact with a surface made from a different material. The electricity generated by TENG devices could replace or supplement batteries for a broad range of potential applications.”

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Alexander Oettl is an assistant professor in Georgia Tech’s Scheller College of Business. The number of times academic articles are cited by subsequent publications is among the measures used to assess scholarly standing. But not all citations are positive ones, and a paper published in the journal Proceedings of the National Academy of Sciences found that as many as one in 50 citations in a top immunology journal were critical in nature.

Negative citations may point out limitations, inconsistencies, or flaws in previous work. The study found that these negative citations tended to originate from scholars who were close to the authors of the original articles in academic disciplines—such as at least 150 miles away geographically.

The researchers, by authors at Georgia Tech, the University of Toronto, and the Massachusetts Institute of Technology, may be the first to systematically quantify and examine negative citations. “Given that we rely so heavily on these citation metrics as measures of quality, it’s important to note that the intent of these citations isn’t homogeneous,” said Alexander Oettl, an assistant professor in Georgia Tech’s Scheller College of Business. — John Toon
Tristan Al-Haddad has transformed a nondescript stretch of concrete jungle in midtown Atlanta with a 33-foot-tall monolithic sculpture. The award-winning piece, *Stealth*, is a series of interlocking anamorphic projections that create a folded three-dimensional form. From the perspective of a viewer walking around the work — which comprises a rectangle and an elongated hexagon in projection — it both expands and collapses in space.

Al-Haddad, an assistant professor in Georgia Tech’s School of Architecture, worked on the piece for more than two and a half years and went through more than 200 iterations of 3-D modeling to get the design just right.

While the piece glows as if it were steel, it is made from concrete.

“We were able to produce highly plastic, very thin forms of concrete,” Al-Haddad said. “When you demonstrate that it can be done in an effective and ubiquitous way, you can start to impact the way in which people imagine concrete can be used. That opens new and exciting design opportunities for everyone.”

A general rule when using concrete is not to go below an inch of thickness. But *Stealth* goes down to just one-eighth of an inch in some areas, Al-Haddad said.

He worked with Sinclair Construction Group and design engineering firm Uzun & Case to build the sculpture, which was commissioned by Cousins Properties.

The sculpture weighs about 70,000 pounds. The structural framework was built in Al-Haddad’s studio and cast-in-place in front of the Promenade Tower. The concrete was poured in 4-foot vertical increments. Eight tons of steel reinforcing bar were cut by hand, bent, and placed in position.

Al-Haddad worked with chemists from Thomas Concrete Group for two years to develop the concrete mix. It had to have high strength, while still maintaining the ability to flow into the structure’s sharply angled shapes.

Both the coarse and fine aggregate for the concrete were from a blue-black Adairsville granite quarried in North Georgia. The mix included iron oxide and carbon pigments for coloring and synthetic macro fibers for crack control.

After casting, the sculpture was diamond-honed to remove any imperfections, and each section was wet polished to give *Stealth* a sheer, reflective bluish-black finish.

The real technical impact of *Stealth*, Al-Haddad said, could be that it eliminates the fear and risk of what others may try in the future.

“This is a demonstration of going beyond the limits of conventional practice,” he said. “When you demonstrate that it can be done, you bring the designers and builders closer together.” — Laura Diamond
SOL-GEL OFFERS RECORD CAPACITOR ENERGY STORAGE

Using a hybrid silica-sol-gel material and self-assembled monolayers of a common fatty acid, researchers have developed a new capacitor dielectric material that provides an electrical energy storage capacity rivaling certain batteries.

If the material can be scaled up from laboratory samples, devices made from it could surpass traditional electrolytic capacitors for applications in electromagnetic propulsion, electric vehicles, and defibrillators.

The new material is composed of a silica-sol-gel thin film containing polymer groups linked to the silicon atoms and nanoscale self-assembled monolayer of an oxyphosphonic acid, which provides insulating properties. The polymer structure blocks the injection of electrons into the sol-gel material, providing low leakage current, high breakdown strength, and high extraction efficiency.

“Sol-gels with organic groups are well-known, and fatty acids such as phosphonic acids are well-known,” noted Joseph Perry, a professor in the School of Chemistry and Biochemistry at Georgia Tech. “But to the best of our knowledge, this is the first time these two types of materials have been combined into high-density energy storage devices.”

The need for efficient, high-performance materials for electrical energy storage has been growing along with the demand for electrical energy in mobile applications. Dielectric materials can provide fast charge and discharge response, high energy storage, and power conditioning for defense, medical, and commercial applications. But it has been challenging to find single dielectric material able to meet all of the material needs.

Hybrid sol-gel materials had shown potential for efficient dielectric energy storage because of their high orientational polarization under an electric field, so Perry’s research group decided to pursue these materials for the new capacitor applications.

The research, supported by the Office of Naval Research and the Air Force Office of Scientific Research, was reported in the journal Advanced Energy Materials.

In emergencies, people may trust robots too much for their own safety, a new study suggests. In a mock building fire, test subjects followed instructions from an “Emergency Guide Robot” even after the machine had proven itself unreliable — and after some participants were told that the robot had broken down.

The research was designed to deter people from relying too much on artificial intelligence. But the researchers were surprised to find that the test subjects followed the robot’s instructions even when they knew from that work that one of the most important factors in a fall is the angle of the landing. Armed with that information, the tests showed that people relying on AI to optimize the sequence of motions that take place during a fall could potentially cause damage to the robot and themselves.

Researchers have demonstrated a new process for rapidly fabricating complex three-dimensional nanostructures from a variety of materials, including metals. The technique uses nanoelectrospinning to provide a continuous supply of liquid precursors, which can include metal ions that are converted into high-purity metal by a focused electron beam.

The process generates structures — such as nanobridges — that would be impossible to make using gas-phase focused electron beam-induced deposition (FEBID) techniques, and allows fabrication at rates up to 1,000 times faster than with the gas-phase technique. And because it uses standard liquid solvents, the new process could take advantage of a broad range of precursor materials.

“By allowing us to grow structures much faster with a broad range of precursors, this technique really opens up a whole new direction for making a hierarchy of complex three-dimensional structures with nanoscale resolution at the rate that is demanded for manufacturing scalability,” said Andrew Fedorov, a professor in Georgia Tech’s George W. Woodruff School of Mechanical Engineering.

In the established FEBID process, an electron beam is used to write structures from molecules adsorbed onto a solid surface that provides support and nucleation sites. The precursors are introduced into the high-vacuum electron microscope chamber in gas phase. High-energy electrons in the beam interact with the substrate to produce the low-energy secondary electrons, which dissociate the adsorbed precursor molecules, resulting in deposition of solid material on the substrate surface.

Fedorov and his collaborators have accelerated the original gas-phase process by introducing electrically charged liquid-phase precursors directly into the high-vacuum of the electron microscope chamber.

The research was supported by the U.S. Department of Energy’s Office of Science and reported in the journal Nano Letters.
THE SOUND OF NANO SCALE MATERIALS

Understanding where and how phase transitions occur is critical to developing new generations of materials for use in high-performance batteries, sensors, energy-harvesting devices, medical diagnostic equipment, and other applications. But there was no good way to study and simultaneously map those phenomena at the relevant length scales—until now.

Researchers from Georgia Tech and Oak Ridge National Laboratory (ORNL) have developed a new, nondestructive technique for investigating these materials by changing their atomic structure and detecting the response of the material to those changes. This approach has been used in ferroelectric materials but has also been applied in other materials, including organic molecules and even the surface of the moon.

A LIGHT TOUCH

Having a light touch can make a hefty difference in how well animals and robots move across challenging granular surfaces such as snow, sand, and leaf litter. New research shows how the design of appendages—legs or wheels—affects the ability of robots as well as animals to traverse weak and flowing surfaces.

Using an air-fluidized bed trackway filled with poppy seeds or glass spheres, researchers systematically varied the stiffness of the surface to mimic everything from hard-packed sand to powdery snow. By studying how running lizards, jacks, crabs—and a robot—moved through those surfaces, the researchers correlated variables such as appendage design with performance across the range of surfaces.

What the scientists learned from this study might help future robots avoid getting stuck in loose soil or on a distant planet.

Making solar energy more cost effective

The cost of installing photovoltaic systems on buildings stems from three main components: the photovoltaic panels, the racking system that holds the panels, and the labor to affix the panels and racking system to the building or structure.

The way the panels are attached to structures is called “balancing of system” for the solar panel. Researchers from the Georgia Tech Research Institute (GTRI) and Georgia Tech’s College of Architecture have been working together to help address balance of system costs, making solar energy a more cost-effective option.

“Photovoltaic cells are going to be mainstream,” said Francisco Valdés, a GTRI research engineer. “They will be part of the building. We started with 143 concepts and narrowed it down to five products, two of which are now in production.”

The Georgia Tech team developed two solutions for attaching the panels—Quad Pod and Anaconda. The Quad Pod is a canopy solution, while Anaconda is a method of attaching the panels to a flat roof. Both systems have been installed in the Atlanta area, and design improvements are underway as the projects transition into the hands of private companies.

POPULAR

Word Gets Around

The 1896 presidential candidate William Jennings Bryan captivated the 1896 Democratic National Convention with a speech in which he called for a new currency standard based on silver rather than gold. Over the next few years, his “Cross of Gold” idea spread across the country, with thousands of newspaper mentions.

But it took 150 years and a collaboration between Georgia Tech data scientist and University of Georgia historians to see exactly how the idea spread. Researchers tracked “Cross of Gold” using U.S. News Map, a database of more than 10 million newspaper pages that help researchers see history with spatial information that hadn’t been available before.

Every historical development has a spatial component to it, and this tool is critical in explaining the “how” and the “why,” noted Claudia Sant, chair of the Department of History at the University of Georgia. “With this new search engine, we now have the ability to see where newspapers were writing about a subject, and how interest in that subject changed over time. It’s a powerful tool for historians and one that can add new light on the past.”

A free service, the database is available at www.usnewsmap.com. Researchers downloaded more than 2 million U.S. newspapers published between 1836 and 1924 that were scanned by U.S. universities with support from the U.S. Library of Congress. Each word that text was then indexed for use in the database, explained Trevor Goodyear, a research scientist in the Georgia Tech Research Institute. (GTRI).

In U.S. News Map, each instance of a term that appeared in the newspapers is represented with a dot, and higher data indicate multiple mentions. Users can move a slider to see how terms pop up in different cities and follow a link to images of the newspaper pages.

“We’ve placed the data onto a map of the United States that allows users to view how the term moved across the country over time,” Goodyear explained. “You can navigate through time to see how each term was used in different locations. You really get a sense for how ideas were transmitted during that time in history.” — JOHN TOON
The world human population is already more than 7 billion — a number that could exceed 11 billion by 2060, according to projections from the United Nations. This rising populace, coupled with environmental challenges, puts even greater pressure on already strained energy resources. Granted, there’s no silver bullet, but Georgia Tech researchers are developing a broad range of technologies to make power more abundant, efficient, and eco-friendly.

This feature provides a quick look at a dozen unusual projects that could go beyond traditional energy technologies to help power everything from tiny sensors to homes and businesses.
teries is problematic. Powering devices in remote locations where changing battery life would be 40,000 times more energy dense than current lithium batteries. Initial applications include military equipment.

Yee believes the betavoltaic devices could ultimately generate between 4 and 18 percent. With continued improvements, researchers have been achieving power conversion efficiencies of 0.5, and we’re currently around 0.1, so we’re not far off,” Yee said. “It can also be used with other heat sources such as natural gas, biomass, and nuclear to directly produce electricity without boiling water and spinning turbines.”

Funded by the Department of Energy’s (DOE) SunShot Initiative, this unique conversion engine has no moving parts. A quick rundown in geek speak: Electricity is generated from solar heat by thermally driving a sodium redox reaction on opposite sides of a solid electrolyte. The resulting positive electrical charge flows through the solid electrolyte due to an electrochemical potential produced by a pressure gradient, while the electrons travel through an external load where electric power is extracted. Bottom line, this new process results in improved efficiency and less heat leaking out, explained Yee.

The goal is to reach heat-to-electricity conversion efficiency of more than 45 percent — a substantial increase when compared to 20 percent efficiency for a car engine and 30 percent for most sources on the electric grid. The technology could be used for distributed energy applications. “A Na-TECC engine could sit in your backyard and use heat from the sun to power an entire house,” Yee said. “It can also be used with other heat sources such as natural gas, biomass, and nuclear to directly produce electricity without boiling water and spinning turbines.”

Funded by the Defense Advanced Research Projects Agency (DARPA) and working in collaboration with Stanford University, the researchers have developed a technology that is similar to photovoltaic devices with one big exception: Instead of using photons from the sun, it uses high-energy electrons emitted from nuclear hyperdecays. Betavoltaic technology has been around since the 1950s, but researchers have focused on tritium or nickel-63 as beta emitters. “Our idea was to revisit the technology from a radiation transport perspective and use strontium-90, a prevalent isotope in nuclear waste,” Yee said.

Strontium-90 is unique because it emits two high-energy electrons during its decay process. That’s more tritium-90’s energy spectrum aligns well with design architecture already used in crystalline silicon solar cells, so it could yield highly efficient conversion devices.

In lab-scale tests with electron beam sources, the researchers have achieved power conversion efficiencies of between 4 and 18 percent. With continued improvements, Yee believes the betavoltaic devices could ultimately generate about one watt of power continuously for 30 years — which would be 400,000 times more energy dense than current lithium ion batteries. Initial applications include military equipment that requires low-power energy for long periods of time or powering devices in remote locations where changing batteries is problematic.

New Breed of Betavoltaics

In another project, Yee’s group is using nuclear waste to produce electricity — minus the reactor and sans moving parts.

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Flexible Generators

Yee’s group is also pioneering the use of polymers in thermoelectric generators (TEGs). Solid-state devices that directly convert heat to electricity without moving parts, TEGs are typically made from inorganic semiconductors. Yet polymers are attractive materials due to their flexibility and low thermal conductivity. Those qualities enable clever designs for high-performance devices that can operate without active cooling, which would dramatically reduce production costs.

The research has developed P- and N-type semiconducting polymers with high performing ZT values (an efficiency metric for thermoelectric materials). “We’d like to get to ZT values of 0.5, and we’re currently around 0.1, so we’re not far off,” Yee said.

In one project funded by the Air Force Office of Scientific Research, the team has developed a radial TEG that can be wrapped around any hot water pipe to generate electricity from waste heat. Such generators could be used to power light sources or wireless sensor networks that monitor environmental or physical conditions, including temperature and air quality.

“Thermoelectrics are still limited to niche applications, but they could displace batteries in some situations,” Yee said. “And the great thing about polymers, we can literally paint or spray material that will generate electricity.”

This opens opportunities in wearable devices, including clothing or jewelry that could act as a personal thermostat and send a hot or cold pulse to your body. Granted, this isn’t done now with inorganic thermoelectrics, but this technology results in bulky ceramic shapes, Yee said. “Plastics and polymers would enable more comfortable, stylish options.”

Although not suitable for grid-scale application, such devices could provide significant savings, he added.
Recycling Radio Waves

Researchers led by Manos Tentzeris have developed an electromagnetic energy harvester that can collect enough ambient energy from the radio frequency (RF) spectrum to operate devices for the Internet of Things (IoT), smart skin and smart city sensors, and wearable electronics.

Harvesting radio waves is not brand new, but previous efforts have been limited to short-range systems located within meters of the energy source, explained Tentzeris, a professor in Georgia Tech’s School of Electrical and Computer Engineering. His team is the first to demonstrate long-range energy harvesting as far as seven miles from a source. The researchers unveiled their technology in 2012, harvesting tens of microwatts from a single UHF television channel. Since then, they’ve dramatically increased capabilities to collect energy from multiple TV channels, Wi-Fi, cellular, and handheld electronic devices, enabling the system to harvest power in the order of milliwatts. Hallmarks of the technology include:

- Ultra-wideband antennas that can receive a variety of signals in different frequency ranges
- Unique charge pumps that optimize charging for arbitrary loads and ambient RF power levels
- Antennas and circuitry, 3-D inkjet-printed on paper, plastic, fabric, or organic materials, that are flexible enough to wrap around any surface
- (The technology uses principles from origami paper-folding to create “smart” shape-changing complex structures that reconfigure themselves in response to incoming electromagnetic signals.)

The researchers have recently adapted the harvester to work with other energy-harvesting devices, creating an intelligent system that probes the environment and chooses the best source of ambient energy to collect. What’s more, it combines different forms of energy such as kinetic and solar, or electromagnetic and vibration.

Although some work remains to scale the printing process, commercialization of the National Science Foundation-supported research could happen within two years.

Power Rubbed the Right Way

Triboelectricity enables production of an electrical charge from friction caused by two different materials coming into contact. Although known for centuries, the phenomenon has been largely ignored as an energy source because of its unpredictability.

Yet researchers led by Zhong Lin Wang, a Regents Professor in Georgia Tech’s School of Materials Science and Engineering, have created novel triboelectric nanogenerators (TENGs) that combine the triboelectric effect and electrostatic induction. By harvesting random mechanical energy, these generators can continuously operate small electronic devices.

The first TENG debuted in 2012. Powered by foot tapping, it generated enough alternating current to power banks of LEDs. Since then the team has adapted enough alternating current to power banks of LEDs.

In another energy harvesting approach, researchers in Georgia Tech’s School of Mechanical Engineering are making advances with piezoelectric energy – converting mechanical strain from ambient vibrations into electricity.

Scientists have been exploring this field for more than a decade, but technologies haven’t been widely commercialized because piezoelectric harvesting is very sensitive to excitation frequency and application dependent, explained Alper Erturk, an assistant professor of acoustics and dynamics who leads Georgia Tech’s Smart Structures and Dynamical Systems Laboratory.

Current piezoelectric energy harvesters rely on linear resonance behavior, and to maximize electrical power. the excitation frequency of the harvester must match the resonance frequency of the harvester. “Even a slight mismatch results in drastically reduced power output, and there are numerous scenarios where that happens,” Erturk said.

In response, Erturk’s group has been pioneering nonlinear dynamic designs and sophisticated computations to develop wide-band piezoelectric energy harvesters that operate over a broad range of frequencies. In fact, one of their recent designs, an M-shaped harvester, can achieve milliwatt level output even for tiny milli-g vibration inputs — a 660 percent increase in frequency bandwidth compared to linear counterparts. “The nonlinear harvesters also have secondary resonance behaviors,” Erturk said, “which could enable frequency up-conversion in MEMS harvesters that suffer from device resonance being higher than ambient vibration frequencies.”

Although electrical output from vibration energy harvesters is small, it is still enough to power wireless sensors for structural health monitoring in bridges or aircraft, wearable electronics, or even medical implants. “Triboelectric harvesting could eliminate the hassle of replacing batteries in many low-power devices — providing cleaner power, greater convenience, and meaningful savings over time,” Erturk said.
Researchers led by Baratunde Cola, an associate professor in Georgia Tech’s School of Mechanical Engineering, have developed the first known optical rectenna — a technology that could be more efficient than today’s solar cells and less expensive.

Rectennas, which are part antenna and part rectifier, convert electromagnetic energy into direct electrical current. The basic idea has been around since the 1960s, but Cola’s team makes it possible with nanoscale fabrication techniques and different physics. “Instead of converting particles of light, which is what solar cells do, we’re converting waves of light,” he explained.

Key to this technology are antennas small enough to match the wavelength of light (about one micron) and a super-fast diode — achieved in part by building the antenna on one of the metals in the diode. Cola describes the process as

- Carbon nanotubes are grown vertically off a substrate.
- Using atomic layer deposition, the nanotubes are coated with aluminum oxide to serve as an insulator.
- Extremely thin layers of calcium and aluminum metals are placed on top to act as an anode.
- As light hits the carbon nanotubes, a charge moves through the rectifier, which switches on and off to create a small direct current. The metal-in-silicate-metal diode structure is fast enough to open and close at rates of 1 quadrillion times per second.

From a performance perspective, the device currently operates just under 1 percent efficiency. Yet because theory matches lab experiments, Colola hopes to increase broad-spectrum efficiency to 40 percent (which compares to 20 percent efficiency for silicon solar cells). Other important benefits include:

- The optical rectenna works at high temperatures, and mass production should be inexpensive. The technology also can be tuned to different frequencies, so the rectenna can be used as a detector or in energy harvesting.

The researchers are now focusing on lowering contact resistance and growing the nanotubes on flexible substrates for applications that require bonding the work has been supported by DARPA, the Space and Naval Warfare Systems Center, and the Army Research Office.

Fuel from the Sky

In another intriguing project, researchers led by Peter Loutzenhiser are leveraging solar energy to convert the combustion process and produce synethsis gas (mixtures of hydrogen, carbon monoxide, and small amounts of carbon dioxide) which can be converted into fuels such as kerosene and gasoline.

“Instead of using fossil resources to create fuel, we are using the byproducts of combustion (water and carbon dioxide) to re-energize the system with the sun,” explained Loutzenhiser, an assistant professor at Georgia Tech’s School of Mechanical Engineering.

The researchers are studying a two-step process using metal oxides that can split water and carbon dioxide. The first step, which occurs between 1100 and 1800 degrees Celsius, thermally reduces or “pulls off” oxygen from the metal oxide material. Then at temperatures of about 300 to 900 degrees Celsius, either water or carbon dioxide is introduced in the second stage. These lower temperatures are favorable for re-oxidation, which enables water to give back oxygen from either the water or carbon dioxide, resulting in hydrogen or carbon monoxide.

“The two steps are important — otherwise the oxygen would recombine with either the carbon monoxide or hydrogen, resulting in the release of heat that would then be lost,” Loutzenhiser said.

The researchers have demonstrated that the technology works at high temperatures, but they are searching for materials that can speed up the reactions and reduce the temperature of the first step. “You want something that can reduce at the lowest possible temperature in the high-temp stage and is capable of re-oxidizing compounds from the carbon dioxide or the water vapor in the second step,” Loutzenhiser explained.

Recently, the group achieved promising results with mixed ionic-organic electronic conducting materials. Now they are trying to tune these materials to break apart either the CO₂ molecules or the water vapor molecules at lower temperatures.

If commercialized, the technology could transform desert areas into fuel farms, Loutzenhiser said: “Instead of pulling fuel out of the ground, we pull carbon dioxide from the air and use the sun to convert it with water into a long-term storage medium that could be shipped and used around the world without changes to transportation infrastructure.”

The researchers have also improved supercapacitors — a technology that could be transformative, according to Loutzenhiser.

“Today’s supercapacitors have only one-tenth the energy density of lithium-ion batteries,” pointed out Meilin Liu, a Regents Professor in Georgia Tech’s School of Materials Science and Engineering. “For the device to give you the same electrical energy, the device would have to be much bigger. Working with C.P. Wong, another Regents Professor, Liu is developing graphene-based supercapacitors that offer significantly increased energy density while maintaining high power and long operational life. The research is funded by ARPA-E.”

Graphene is a two-dimensional material that conducts electricity better than copper and is both lighter than steel and 100 times stronger. Yet graphene has a tendency to stack together and form graphite. To prevent this, the researchers place molecular spaces between the graphene sheets, creating a 3-D porous structure that demonstrates a capacitance of 400 Faradays per gram — four times higher than current supercapacitors.

The researchers have also improved the energy density by densifying voltage using two different electrode materials (one positive and one negative). “Each node material has its own operating window of potential, and we optimize the nanofab structure to achieve the highest energy density,” Liu explained.

With these new developments, the researchers are approaching supercapacitors that can be as small as batteries, but charged and discharged faster and cycled for much longer, Liu said.

“This new breed of supercapacitors could replace batteries, providing cleaner, safer, and more robust power for many applications, from portable electronics to electric vehicles and smart grids.”
MONOLITHIC MICROSCALE HEAT PUMPS

Proving that good things come in small packages, researchers led by Srinivas Garimella have developed a novel textbook-sized cooling system that operates on waste heat rather than electricity. The underlying technology has been used in very large-scale installations, such as hospitals and university campuses, explained Garimella, a professor in Georgia Tech’s School of Mechanical Engineering. Yet his team takes the science to a new level by working at the micro-scale and creating a self-contained unit. How it works: Extremely small passages are etched into thin sheets of metal with different areas representing different components. Working fluids flow in the same order as they would in a larger system, albeit in one space. The minimization of plumbing tubes and outlets translates into greater compactness — and lower price tag.

Other advantages:

- No synthetic refrigerants are used, and no fluid is required, which further lowers costs and increases safety.
- No compressor is needed and there are few moving parts, decreasing noise and increasing reliability.
- Modular design allows units to be configured to generate anywhere from a few watts to tons of kilowatts of cooling or heating.

Since unveiling a proof-of-concept unit in 2009, the researchers have developed heat pumps with cooling capacities of one and two refrigerant tons (Capacity of current residential units ranges from one to four refrigerant tons). Efficiency has been substantially improved, and fabrication techniques have also been improved to enable mass production.

“Although initial cost to consumers might be higher than traditional heat pumps, lifecycle costs should be comparable because of lower operating costs,” Garimella said, noting that field tests are slated for late this year, and the technology might be ready for commercialization by 2017. The researchers have also adapted the technology to provide cooling using waste heat from diesel-driven generators at military bases, where ambient temperatures are extremely high. “Not only is diesel fuel very expensive to transport, there are also risks to humans in delivering the fuel,” Garimella said. “Using the energy in the diesel fuel to the fullest extent by providing power as well as cooling through these units, without consuming additional prime energy, will lower overall costs and increase personnel safety.”

The research has been supported by ARPA-E, Department of Energy, U.S. Army, Naval Facilities Engineering Command, Georgia Research Alliance, and Atlanta Gas Light.

Researchers in Georgia Tech’s School of Mechanical Engineering are working on major makeovers for power plants, introducing innovations that range from revamped power cycles to new infrastructure materials.

In one project, steam is being replaced with supercritical carbon dioxide (SCCO₂) as the working fluid to operate turbines and produce electricity. SCCO₂ results when carbon dioxide is subjected to pressure above 74 megapascals and temperatures above 31 degrees Celsius. This magical state, somewhere between a liquid and a gas, provides high fluid density, thermal conductivity, and heat capacity.

SCCO₂ is currently used in environmentally friendly dry cleaning and coffee decaffeination. In energy applications, its high density and compressibility would enable generators to extract more power from turbines, explained Devesh Ranjan, an associate professor of fluid mechanics. “Equipment could be made from top-notch materials, yet dramatically smaller, which would reduce production costs.”

Another plus: the unique cooling properties of SCCO₂. “Most power plants are near a lake or river because they need lots of water to cool them,” Ranjan said. “Because the heat transfer coefficient is very high with SCCO₂, you can do dry cooling in an arid environment such as the desert, which is bad for solar collection.”

Using SCCO₂ in concentrated solar plants could push thermal efficiencies from 45 to 60 percent, enough to be competitive with fossil fuel, said Asegun Henry, an assistant professor of heat transfer, combustion, and energy systems. “Yet this requires higher operating temperatures — 800 degrees Celsius compared to current temperatures below 600 degrees — and current heat exchangers literally can’t take the pressure.”

To resolve this, Henry and Ranjan are working with Purdue University researchers to develop new heat exchanger that can withstand extremely high temperatures and pressures, a project supported by DOE SunShot funding.

Ken Sandhage, a former Georgia Tech professor now at Purdue’s School of Material Engineering, has developed a process for inexpensively fabricating a high-temperature composite material into complicated 3D shapes. In addition to making solar power more competitive, the heat exchangers could also be used with SCCO₂ to boost efficiency in fossil fuel power plants. “More efficiency means less carbon dioxide emissions per kilowatt produced,” Henry said.

T.J. Becker is a freelance writer based in Michigan. She writes about business and technology issues.
ROLLING ROBOTS
RESEARCHERS WORK TO AVOID POTHOLES AND PITFALLS ON THE ROAD TO AUTONOMOUS VEHICLES
BY RICK ROBINSON • ILLUSTRATION BY TAVIS COBURN
CAR-DRIVER COOPERATION

Many researchers believe semi-autonomous vehicles will dominate during the years or decades needed to sort out the complexities of fully autonomous transport. One key question: How can a semi-autonomous car or truck share driving responsibilities with people smoothly and safely?

At Georgia Tech’s Sonification Laboratory, Professor Bruce Walker pursues studies on the use of sound to convey information to people whose eyes are otherwise engaged—a mission focused on a procedure or a firefighter hampered by smoke. Walker, who also works jointly in the School of Psychology and School of Interactive Computing with a focus on engineering psychology, is testing interface approaches that would allow a human riding in a semi-autonomous car to search the Web or read an ebook while also staying reliably informed about vehicle operation.

One key research focus on situational awareness, explains Walker, a member of Georgia Tech’s GVU Center as well as its Institute for People and Technology. Drivers of conventional cars must be constantly aware just to stay in a lane, but in a semi-autonomous vehicle with features like advanced lane control, occupants could work and play without much regard for the road or other drivers.

“Inevitably, however, there are going to be situations where the autonomous processes — the computer vision, the guidance smarts, the GPS signal — will fail and control has to be handed off to a human,” he said. “The system needs to be able to keep the driver informed of any potential problems — my contention is that we can never let the driver lose situational awareness.”

Critical to maintaining this shared awareness is developing ways for a semi-autonomous guidance system to monitor itself — essentially, to maintain confidence in its own ability to handle what’s ahead. Under this approach, when a guidance system’s self-confidence falls below a certain point, the vehicle will alert the driver to take over.

To achieve effective vehicle-human communication, Walker’s team is studying how to use sound to relay information to the driver.

At the Georgia Tech Autonomous Racing Facility, researchers are studying a small-scale autonomous vehicle that resembles a dirt track. The work will help engineers understand how to help driverless vehicles face the risky and unusual road conditions of the real world.

This article takes a look at some of the research currently underway at Georgia Tech related to self-driving vehicles.
should be so aggressive that they alarm the occupants, or so passive that people become frustrated.”

**DEVELOPING CONTROL LANGUAGE**

Driving simulators are valuable tools for autonomous vehicle research. In the Human-Machine Interface Laboratory, Wayne Li is investigating the role of language in the critical task of autonomous-vehicle control. He wants to know how control language—what people see, feel, and touch inside a vehicle—can make users confident even when they don’t have conventional full control.

Li is working with a Georgia Tech-built testbed, called Sonification Laboratory, a research effort sponsored by the U.S. Department of Transportation. In the Human-Machine Interface Laboratory, a research effort sponsored by the U.S. Department of Transportation, the researchers are testing a wide variety of background sounds. The researchers are weighing different approaches for conveying escalating levels of concern, from “all-systems go” to “intervention needed.” The goal is to keep drivers in the loop without alarming them.

To assess how people coexist with multiple scenarios, the team is using three driving simulators, including a minivan located next to the National Advanced Driving Simulator group at the University of Iowa. This realistic setup combines advanced software with full-size control pedals and steering wheel, multiple plasma screens, and even a genuine car seat. Eye-tracking equipment and physical response monitors track a user’s interactions with the visual driving routines.

Panasonic Automotive, currently a dominant producer of automotive control systems such as cruise control, has been paying close attention to Walker’s work. John Avery, engineering manager for the Panasonic Innovation Center in Georgia Tech’s School of Aerospace Engineering, is a joint effort of Georgia Tech’s School of Industrial Design, where Li is the Oliver Endowed Professor of Practice, and the School of Mechanical Engineering, School of Interactive Computing, and School of Psychology. The project is funded by General Motors Corporation.

“Our work involves exploring the different types of control schema that will function best as we move toward levels three, four and five autonomous and level four autonomous cars,” Li said. “Maybe at level three there’s a teacher in school anymore—maybe it’s a joystick—and maybe there’s no speedometer or instrument cluster either, since a semi-autonomous car would automatically obey speed limits.”

The Sonification Laboratory cooperates with Bruce Walker’s Sonification Lab, helping to coordinate and share expertise. Both labs use miniSim software from the National Advanced Driving Simulator group to help support their testbeds’ simulation and evaluation capabilities.

Li envisions cars with small transparent windshields that give a view of the road while also providing important vehicle information along with email, Web pages, and video. If the windshield image and audio are displayed correctly, it could negate the reason a person in the driver’s seat to prepare to take over.

“The automatic transmission, which first appeared about 1950, was a terrible design, and it took decades for it to improve to the point where in the U.S. it has almost full acceptance,” Li said. “Autonomy is going to be the same way—the long-term state of the system.”

**AUTONOMOUS RACING TEST TRACK**

A collaborative research team is using scale-model racing cars to explore methods for keeping an autonomous car under control—or rather to help it keep itself under control.

At the Georgia Tech Autonomous Racing Facility, researchers from the School of Interactive Computing (IC) and the Daniels Engineering Advanced Product Development (AE) are racing, sliding, and jumping these one-fifth-scale cars at the equivalent of 90 mph. The goal: to develop maneuvering techniques that can keep an autonomous vehicle on the road and its occupants safe.

“A collaborative research team is using scale-model racing cars to explore methods for keeping an autonomous car under control—or rather to help it keep itself under control.”

His work has thus far turned up concerns that include:

- **Disruption and danger:** The presence of autonomous cars on roadways could disrupt traffic flow for a number of reasons. Robotic components that are not precise or timely would give way to aggressively driven conventional vehicles. That could become a big problem at rush hour, for example, as drivers entering a highway may find they can cut out the distinctive-looking self-driven vehicles, creating shockwaves that slow or stop traffic. Worse, irresponsible drivers or pedestrians knowing how autonomous vehicles are programmed, might play dangerous road games and physically challenging the robots to make them swerve away.

- **Surface street bottleneck:** Multiple at a forecast that highly autonomous traffic will increase traffic flow on main arteries and cause traffic jams in tight, high-speed formations that respond instantly to changes in speed or conditions. But one result could be gridlock when this greater volume of vehicles hits city streets that still use conventional traffic signals.

- **Legislative gridlock:** The potential problems between autonomous car drivers and conventional vehicles could somehow spark legislation efforts to ban driven cars, a move that’s sure to be controversial. “I am highly doubtful that any government entities would ban human beings from driving for the foreseeable future,” Hunter said. “This is not going to be a short-term transition. A mixed fleet of human-driven and robotic vehicles—with any number of issues and challenges—is going to be the long-term state of the system.”

**MODELING MIXED-FLIGHT CONFLICTS**

Michael Hunter, an associate professor in Georgia Tech’s School of Architecture, is a joint effort of Georgia Tech’s School of Civil and Environmental Engineering, uses computer models to study the management and operation of future roadways.

His work is looking at a variety of possible traffic scenarios as semi-autonomous and fully autonomous vehicles become reality. Hunter directs both the University Transportation Center, a research effort sponsored by the U.S. Department of Transportation that involves Georgia Tech and three partner universities.

“An autonomous vehicle should be able to handle any condition, not just drive on the highway under normal conditions,” said Tsiotras, an expert on the mathematics behind rally car control. “Some researchers custom build the team — use powerful graphics processing units (GPUs) onboard to supply the computation necessary for autonomous navigation and data capture. Using GPUs-based guidance, multiple parallel GPUs employ advanced mathematical techniques to provide the real-time functionality needed to solve a wide variety of math problems at high speeds. Emotional measurement sensors provide additional velocity data.

“Our vehicles are unique because they’re fully autonomous — there’s no throttle, no radio connection, and all data processing is done on the vehicle,” said Rehg, who is a member of the Institute for Robotics and Intelligent Machines at Georgia Tech. “We know of studies that are using full-size racing cars and human drivers, but there are some clear advantages to being smaller — we can maneuver our cars very aggressively, and if we crash, no one’s hurt and it’s easy and low-cost to replace the components.”

Computers, he added, can readily convert the information collected from these small cars, so that their performance data becomes comparable to the performance expected from a full-size vehicle.

Designing and building the right vehicle was a complex undertaking. Challenges included integrating the onboard computer, sensors, actuators, and software so they work together seamlessly and robustly. The team used gasoline engines at first, but later turned to electric motors that combine small size with plenty of power.

In one series of experiments, the researchers utilized maneuvering and handling techniques that control landings by spanning or slowing a vehicle’s wheels in mid-air — into the guidance systems of its autonomous cars. Other efforts include vision-based control for autonomous vehicles to augment GPS guidance, and the ability for vehicles to anticipate deadly T-bone collisions before impact and then maneuver automatically to better protect occupants.

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**EXPLOITING THE ELECTRIC GRID**

The autonomous vehicles of the future may be powered largely by electric engines, which offer energy advantages in on- and off-road urban driving. If so, the presence of millions of high-capacity car batteries could have major implications for the U.S. electric grid. In the future, electric vehicles will be able to supply power to the grid during peak usage times, or to ‘charge back’ electricity to the grid during periods of low demand, according to a recent study.

“Vehicle-to-grid capabilities could have major implications for the U.S. electric grid.”

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“Surface street bottleneck:** Multiple at a forecast that highly autonomous traffic will increase traffic flow on main arteries and cause traffic jams in tight, high-speed formations that respond instantly to changes in speed or conditions. But one result could be gridlock when this greater volume of vehicles hits city streets that still use conventional traffic signals.

**Legislative gridlock:** The potential problems between autonomous car drivers and conventional vehicles could somehow spark legislation efforts to ban driven cars, a move that’s sure to be controversial. “I am highly doubtful that any government entities would ban human beings from driving for the foreseeable future,” Hunter said. “This is not going to be a short-term transition. A mixed fleet of human-driven and robotic vehicles—with any number of issues and challenges—is going to be the long-term state of the system.”

**THE AUTOMATIC TRANSMISSION, WHICH FIRST APPEARED ABOUT 1950, WAS A TERRIBLE DESIGN, AND IT TOOK DECADES FOR IT TO IMPROVE TO THE POINT WHERE IN THE U.S. IT HAS ALMOST FULL ACCEPTANCE. AUTONOMY IS GOING TO BE THE SAME WAY – ACCEPTANCE WILL BE GRADUAL.**

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Functional autonomous vehicles on the road,” Pokutta said. White House representatives and others at a National Science Systems Engineering, recently co-authored a white paper for Assistant Professor in Georgia Tech’s School of Industrial & convience people that automation really is able to protect them.” That approach situation before it happens, it could instantly advise the driver of you off,” Boots said. “If your car can perceive the other vehicles and other performance elements. Byron Boots, an assistant professor in Georgia Tech’s School of Interactive Computing, is performing a statistical analysis on sensor data from a large fleet of level-two vehicles with driver-assistance capabilities. Working with sponsor BMW AG, Boots and his team are investigating the cars’ ability to predict when a potentially hazardous event is imminent and then effectively communicate the situation. Driver assistance, Boots said, is getting a lot of attention from many car makers. Companies are exploring the theory that advising the driver of impending danger could result in a better driving experience than having control suddenly — and alarming — twisted away. “For example, you may be entering a near-miss situation where another vehicle is about to merge into your lane, cutting you-off,” Boots said. “If your car can perceive the other vehicles on the road and use machine learning to predict the dangerous situation before it happens, it could instantly advise the driver of the hazard rather than just taking over control. That approach may not just help to make transportation safer, but also help convince people that automation really is able to protect them.”

BRIEFING THE GOVERNMENT

The advent of autonomous transport has the attention of government. Sebastian Pokutta, who is David M. McKelvey Family Assistant Professor in Georgia Tech’s School of Industrial & Systems Engineering, authored a white paper for the Computing Community Consortium that was presented to White House representatives and others at a National Science Foundation workshop. “Many automakers believe that by 2020 we can have fully functional autonomous vehicles on the road,” Pokutta said. “But for that to happen, there have to be legislative and policy decisions that address a number of critical technology, infrastructural and societal issues. Some of the key points in Pokutta’s analysis include:

• High-speed platooning of cars and trucks could translate into faster commute times. That in turn could add to urban spread as people move farther out into the hinterlands. Moreover, car sharing could mean fewer vehicles will be continually in use, lowering demand for parking and potentially changing urban land use.

• Self-driving prototypes rely heavily on special physical and mapping infrastructure. Extensive investment will be required to bring those kinds of infrastructure changes to the whole nation or to find other ways to overcome these limitations. Even then, self-driving cars may lose their bearings in unexpected situations such as construction, detours, road closures, or unusual weather conditions.

• The GPS-dependent mapping systems that guide autonomous vehicles must be made 100 percent reliable. If signals cut out in bad weather, under leafy groves or inside buildings and tunnels, serious problems could ensue.

One huge benefit from self-driving vehicles could be a major reduction in traffic accidents. Every year 40,000 people die on U.S. roads, and drunk driving results in an estimated $200 billion in costs, Pokutta said. “Autonomous systems taking control away from impaired or deranged operators — in trains and aircraft as well as motor vehicles — could save many lives and a great deal of money.”

PLANNING FOR FREIGHT VEHICLE AUTONOMY

Increasing automation won’t affect the travel of freight vehicles as much as every type, from tractor-trailers to delivery trucks, will also be changed by autonomy in ways that aren’t yet known. A team led by Catherine Ross, Harry West Professor in Georgia Tech’s School of City and Regional Planning (SCaLP), and Tim Welch, an assistant professor in SCaLP, is investigating what may happen as freight vehicles adopt technology that lets them communicate with one another. They could start to drive in tightly packed groups — including high-speed convoys on interstate roads — and follow more efficient routes based on real-time road conditions.

“Eventually the entire human aspect of many freight deliveries — or at least the travel part of them — could become autonomous,” Welch said. “We’re studying what that development might look like in the next five, 10, or 15 years.” Planners will have to develop new approaches to make current road systems more adaptable to autonomous traffic movement. Analytical policies and legislation will be needed to make the construction of new highway and street infrastructure to accommodate the ensuing changes over the long term.

The team is working under a grant from the Transportation Research Board, which is part of the National Academy of Sciences under the National Cooperative Highway Research Program. The project, a joint effort with Ron Allen Hamilton Jr., is a national research effort. “The time horizon for a fully autonomous fleet of any vehicles, passenger or freight, is going to be pretty long one,” Welch said. “Managing that entire process over the long term is going to be a challenging task.”

ANTICIPATING MARKET CHANGES

Vivek Ghosal believes that once the autonomous revolution becomes established, the consequences that underpin the department of a long-planned department will not be the same. Ownership, liability, and mandate for propulsion could all change in major ways. And, like others, he believes the conversion process will be costly and that both government and industry will have to pick up a very large bill. Whether cars are semi-autonomous or fully autonomous, electric or fuel cell powered, they will require wide-scale improvements in roads, traffic signals and controls, road markings, and signage. They’ll also need a new charging/fueling infrastructure that today barely exists.

Even if you could let level-four autonomous cars out on the streets right now, there would be serious problems,” said Ghosal, an auto industry specialist who is Richard and Mary Imman Professor in Georgia Tech’s School of Economics. “Major infrastructure investments are needed to operation- alize this technology.”

Observations from Ghosal’s research include:

• Ownership of cars could substantially reduced under an autonomy-centered paradigm. Even today, car-sharing mar-kets in Europe are expanding quickly, and major car makers there are struggling to compete with Car2Go, Zipcar, and others. The combination of quickly available level-four cars and extensive car sharing will likely produce lower demand for personally owned automobiles.

• Changes in ownership patterns will likely propel current automotive, lending, and insurance markets into unshortened territory, as consumers gradually learn to regard cars as a transportation service rather than a purchase.

• Self-driving vehicles are essentially information technology-enabled devices, a fact that software companies realize. Ghosal believes the autonomous prototypes being developed by companies like Google and Apple aren’t aimed at starting new car manufacturing corporations but are instead focused on developing definitive operating systems for autonomous control. This proprietary software could become a costly necessity for established automotive manufacturers as they evolve driverless vehicles.

Said Ghosal: “This is perhaps the most significant disruption in this industry since the invention of the assembly line by Ford.”

One thing is certain: The self-driving revolution is on its way. What isn’t known is what form it will take as it becomes a reality. Georgia Tech research teams will continue to study and develop effective real-world approaches as the trend continues.

Rick Robinson is a science and technology writer in Georgia Tech’s Institute Communications. He has been writing about defense, electronics, and other technology for more than 20 years.
INNOVATION ADDRESSES RISING THERMAL CHALLENGES IN MOBILE DEVICES, COMPUTERS, AND DATA CENTERS

BY JOHN TOON
In the struggle to improve the performance of mobile devices such as smartphones, extending battery life is just one part of the effort. System designers must increasingly worry about removing heat, an unwanted byproduct of watching a YouTube video, shooting a selfie, or updating a Facebook page. In the same way that physical limits on the size of transistors may制约 the performance growth promised by Moore’s Law (the expectation that computer processing power will double about every two years), the challenge of removing heat from ever-smaller transistors also poses a threat to continued efficiency improvements. The resulting tradeoffs will affect everything that relies on integrated circuits—from mobile phones and tablets all the way up to high-performance computers and data centers that size of football fields.

At Georgia Tech, researchers are addressing these thermal challenges in broad and fundamental ways. Their efforts include designing chips that operate with less power, providing new forms of cooling, and optimizing data center operations.

“The challenges on the small scale are very different from the challenges at the large scale,” said Yogendra Joshi, a professor in Georgia Tech’s School of Mechanical Engineering, whose research group studies thermal challenges in a comprehensive way. “Everyone wants more capabilities in the devices they are using, but there are tradeoffs to be made at each level.”

DEIZNI NG CHIPS FOR THERMAL MANAGEMENT

The whirring fan of a laptop computer is the closest most consumers come to the challenge of thermal management in electronic devices. But the issue really begins much deeper in whatever system they are using, with the design of integrated circuits. In these ICs, billions of transistors carry out computer operations using electrical charges, producing heat that must be removed.

Designers must precisely control temperatures from going beyond levels that can cause a silicon meltdown. But even temperatures below the damage threshold can cause current leakage and reduce performance, so thermal issues have become a critical component of modern IC design.

“Until recently, whenever transistors became smaller, they required correspondingly less power, so you could double the number of transistors on an integrated circuit and the power density remained roughly constant,” noted Sudhakar Yalamanchili, a Regents Professor in Georgia Tech’s School of Electrical and Computer Engineering, whose research group studies thermal challenges at the large scale. “Now, as we double the number of transistors, the on-chip power density increases, which is not sustainable because eventually we will hit the point where heat cannot cool the device.”

The world’s information technology industry has grown accustomed to continual performance increases that boost productivity. Researchers like Yalamanchili are looking at new computing techniques to continue that beneficial trend. “There is only so much heat that you can extract from a device cost-effectively, and that is how much power you can burn in that much volume,” he said. “The amount of power you can burn, in turn, determines how much the transistors can consume, which controls how many transistors you can operate concurrently. And the number of active transistors determines how much performance you can get.”

There are strategies for getting the most out of the available energy. One is increasing the use of special-purpose accelerators that are more efficient than general-purpose chips for certain applications; for example, rewriting code to use graphics-processing units (GPUs), the more energy-efficient processors originally developed to handle graphics. Another is reducing the movement of data on chips, a strategy of special interest to Yalamanchili.

“Moving a data bit will soon take more energy than the computing operations performed with it,” he explained. “We have to minimize data movement, and this will be a fundamental shift in how computing is done. To continue performance scaling with Moore’s Law, we are going to have to redesign systems to be centered around data and memory systems rather than the CPU.”

Other strategies may involve implementing alternative computing models, such as neural networks, inspired by our understanding of how the brain operates. Also, new materials and devices such as conducting films and carbon nanotubes may replace traditional complementary metal-oxide semiconductor-based systems.

Ultimately, the future of computing will depend on a different set of tradeoffs, with energy use—governed by cooling—an increasingly important driver.

“It’s not an interdisciplinary research question,” Yalamanchili said. “You have to be able to understand the characteristics of devices, the design of architectures, the demands of applications, and the physics of the overall environment. Industry wants to keep that performance scaling going, and to do that, we are going to have to be more cross-disciplinary.”

COOLING MOBILE DEVICES

It seems there’s now a smartphone in nearly every pocket or purse. These handheld computers can run basic business applications, shoot video, give directions, play games, browse the Web, gather weather updates, send email—and even make phone calls.

Battery life for these mobile devices has become a major issue for heavy users, but addressing the power challenge is much more complex than it seems. Smartphones and tablet computers have only the most rudimentary passive cooling capabilities. Heat flows to the case, where it dissipates to the environment—or to the user’s body. So having more battery power won’t necessarily translate into more performance.

“The thermal management options for these small devices, both phones and tablets, are extremely limited,” Yalamanchili said. “You can’t have a fan and you can’t have a heat sink. There are some real physical limits on what you can do related to the amount of physical space available and how tightly the components are packed. That limits the performance you can get.”

“WE HAVE TO MINIMIZE DATA MOVEMENT, AND THIS WILL BE A FUNDAMENTAL SHIFT IN HOW COMPUTING IS DONE.”

Sudhakar Yalamanchi, a Regents Professor in Georgia Tech’s School of Electrical and Computer Engineering, is studying how design can address thermal issues in integrated circuits.
The temperature of the device case must be kept low enough — less than about 45 degrees Celsius — to avoid alarming users, while internal temperatures have to remain low enough to avoid damage. Only a few watts of power can heat phones to those limits.

One promising development has been developed in a laboratory led by Joshi and Saibal Mukhopadhyay, where then-Ph.D. students Wen Yueh and Zhimin Wan have achieved what is believed to be the first microfluidic cooling of a commercial system-on-chip for a mobile device. Using deionized water circulated by a tiny peristaltic pump, the experimenters showed that liquid cooling could reduce energy use by 15 to 20 percent — even after accounting for the pump power — by keeping the chip running cooler.

Beyond mobile devices, the work could have implications for robotic vision systems, for example, and other devices that use power-constrained chips in systems with small form factors. The research was supported by Sandia National Laboratories, the Semiconductor Research Corporation, and Qualcomm.

LIQUID COOLING FOR FPGA CHIPS

Using microfluidic passages cut directly into the backs of field-programmable gate array (FPGA) devices, another Georgia Tech research team put liquid cooling just a few hundred microns from where the transistors are operating.

The new technology could allow development of denser and more powerful integrated electronic systems that would no longer require heat sinks or cooling fans on top of the integrated circuits. Working with 28-nanometer FPGA devices, the researchers demonstrated a monolithically cooled chip that can operate at temperatures more than 60 percent below those of similar air-cooled chips.

In addition to enabling more processing power, the lower temperatures can mean longer device life and less current leakage. The cooling comes from simple deionized water flowing through microfluidic passages that replace the massive air-cooled heat sinks normally placed on the backs of chips.

“We believe we have eliminated one of the major barriers to building high-performance systems that are more compact and energy efficient,” said Muhannad Bakir, a professor in Georgia Tech’s School of Electrical and Computer Engineering.

“We believe that reliably integrating microfluidic cooling directly on the silicon will be a disruptive technology for a new generation of electronics.”

Supported by the Defense Advanced Research Projects Agency (DARPA), the research is believed to be the first example of liquid cooling directly on an operating high-performance CMOS chip.

To make their liquid-cooling system, Bakir and graduate student Thomas Sarvey removed the heat sink and heat-spreading materials from the backs of stock Altera FPGA chips. They then etched cooling passages into the silicon, incorporating silicon cylinders approximately 100 microns in diameter to improve heat transmission into the liquid. The silicon layer was then placed over the flow passages, and ports were attached for the connection of water tubes.

With a water inlet temperature of approximately 20 degrees Celsius, the liquid-cooled FPGA operated at a temperature of less than 24 degrees Celsius, compared to an air-cooled device that operated at 60 degrees Celsius.
COOLING MASSIVE DATA CENTERS

In a one-story brick building in Georgia Tech’s North Avenue Research Area, cooling fans inches of computer servers whine as a large air-conditioning system blows cool air into the raised floor below them. The cooled air rises through servers and into an air return built into the ceiling. This data center simulator operates much like the massive facilities that host cloud operations for companies such as Facebook or Microsoft, as well as for innumerable smaller organizations.

But as much as half of the power consumed by such data centers doesn’t go to operate computers. Instead, it’s consumed by the huge air-conditioning systems that carry off the heat generated by the computers. Depending on utility rates and other factors, annual energy bills for such facilities can total several million dollars, providing a research agenda for scientists like Joshi, who studies a broad range of data center energy issues.

“Air flow management is a very important issue inside these facilities,” he noted. “We are studying how air comes up from the perforated tile floor, where it goes, and how we can change that direction. Our simulator allows us to study the critical air flow issues.”

In theory, cooled air is supposed to flow up from the floor through perforated floor tiles, into the server cabinets and then up into the ceiling. Cold air is supposed to be separated from warm air, and each machine is supposed to be kept within a certain range of operating temperatures.

“Ideally, you get all sorted problems with short-circuiting, in which hot air ends up in the cold aisle,” Joshi noted. “We use laser diagnostic equipment, wireless sensors, and other techniques to study how to minimize that with careful air flow control. Using that information, we’re developing techniques for improved air flow management.”

Most commercial data centers use air cooling, and big data center operators use a range of techniques to cool their energy bills, including locating facilities in cold climates such as Chicago or Buffalo, where outside air can replace air conditioning for significant parts of the year.

Unfortunately, the need to provide rapid response — critical to many business applications — dictates that data centers be located close to where the data is needed, so Joshi and others are studying how to use those cooling dollars most effectively.

Development of high-performance computer centers, with their growing appetite for energy, adds urgency to that effort.

“I expect to see a segmented marketplace,” Joshi said. “There will be different kinds of data centers, with one trying to optimize the utilization of the power consumed. The other will optimize the utilization of the compute allocation, the storage allocation, and the applications.”

Modeling being done by Gavrilovska and her colleagues focuses on how thermal needs fluctuate based on operations like those, the software stack in use, the time of day, and other factors. But cooling now tends to be allocated without accounting for those factors, meaning as much as 30 percent of energy expenditures may be unnecessary. Addressing that issue will require more communications between data center operators and tenants — and better modeling.

“We’ve been building a fine-grain, closed-loop system that brings in a lot of data from different levels, including the hardware, the system software stacks, and the applications,” Gavrilovska explained. “We are also building a metering capability so we can account for the overall energy implications of individual applications.”

“A single click — a search through a set of products, for example — can generate hundreds or even thousands of actions. A page is displayed with a database operation, while an algorithm suggests related products, information about user interest is aggregated, and fraud detection software is launched.”

CO-DESIGN OF COMPUTING, SOFTWARE, AND COOLING

Computer servers, system software, and cooling equipment are now designed independently and brought together in the data center. Ada Gavrilovska would like to change that.

A senior research faculty member in Georgia Tech’s College of Computing and the Center for Experimental Research in Computer Systems (CERC), Gavrilovska sees integration as the way to control energy costs, especially as more high-performance computing systems come online and computing continues its move to the cloud.

Only about 5 percent of data centers are operated by companies such as Google, which can carefully control operating conditions to boost efficiency through advanced cooling solutions or because they know their equipment and what’s being processed. Other data centers still have tremendous overhead associated with cooling. Plus, they often serve multiple clients, run many highly dynamic applications, and don’t know what’s generating heat inside the server racks.

“Traditionally, on the system side, we only focused on managing the compute allocation, the storage allocation, and the provisioning of different services in the data center,” Gavrilovska said. “The primary driver was optimizing the utilization of the machines and guaranteeing performance. In many cases, there was so much focus on performance that it didn’t matter how much it cost for cooling.”

In reality, you get all sorts of problems with short-circuiting, in which hot air ends up in the cold aisle,” Joshi noted. “We use laser diagnostic equipment, wireless sensors, and other techniques to study how to minimize that with careful air flow control. Using that information, we’re developing techniques for improved air flow management.”

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Server cooling must be allocated to prevent sporadic heavy-use “hot spots” from overheating many machines at once, cooling systems that provided. System designers can help by distributing workload among servers to avoid these hot spots, and by consolidating operations where possible, allowing unused machines to be shut down. Still, Gavrilovska pointed out, there is a lot of opportunity to further close the gap through better understanding of the workload and its implication for energy use, heat generation, and cooling demand so that energy-saving decisions can lead to benefits with minimized risks.

The research is supported by the National Science Foundation, the U.S. Department of Energy, and several companies with interest in data centers. With the growing demand for high-performance computing, such coordination and integration can’t come soon enough, Gavrilovska said.

“The cost of energy is becoming very significant,” she said. “If we don’t change the way we are doing things, a simple loop operation on an esnecale computer could require megawatts of power. Competing at this scale will very quickly become impractical.”

John Toon is editor of Research Horizons magazine and director of research news at Georgia Tech.
MANUFACTURING SUCCESS

GEORGIA MEP HELPS MANUFACTURERS COMPETE AND GROW

STORY BY PÉRALTE C. PAUL  PHOTOS BY ROB FELT
he challenge was clear enough for John Anker. He wanted to increase operational efficiencies in his company, AnkerPak, the manufacturing and packaging company he founded in 2004, based in Columbus, Georgia. “We’re a young company and costs are critical,” he said. Competing against other manufacturing and packaging companies, particularly from Mexico and China, adds even more pressure, he added. “We’re always looking for ways to reduce our costs, increase efficiency, and implement strategies that result in a real and meaningful monetary tangible return, and I think that’s most important to a young company, tangible returns such as cash flow.”

So Anker did what most executives in his situation would do: Seek the advice of an outside consultant. The first organization he worked with was a firm based in Chicago, but it wasn’t exactly a good fit. Sharing his situation with fellow entrepreneurial CEOs in Columbus, he asked for recommendations. “I said, ‘Who have you used that showed they cared about your business and gave you a good result,’” Anker recounted. “Somebody in that peer group said, ‘You really ought to talk to Derek Woodham at Georgia Tech.’”

Woodham serves West Georgia as a region manager for the Georgia Manufacturing Extension Partnership (GaMEP). A federally funded program of Georgia Tech’s Enterprise Innovation Institute, GaMEP is part of the National MEP network and is supported by the National Institute of Standards and Technology. GaMEP’s mission since it was established at Georgia Tech in 1960: To be a resource and partner available to help manufacturers across Georgia, said Karen Fite, GaMEP’s director. According to the U.S. Census Bureau, Georgia is home to about 7,300 manufacturers.

“Our goal is to be able to help them grow and remain competitive,” Fite said. “For us, that means we want to meet them where they are, we want to understand what their current needs are, and we also want to help them look beyond their immediate challenge in order to think strategically not only about operational excellence, but organizational excellence.”

Manufacturing is an important component of Georgia’s economy; in fact, it’s the second-largest private business industry after agribusiness. Manufacturing employs 365,000 people across the state and accounts for about 11 percent of Georgia’s $493 billion economy.

‘A GREAT RESOURCE’

Anker, the Columbus business owner, had two initial goals he hoped Woodham could help him with: One was to increase operational efficiencies and productivity in the manufacturing plant. The other was to plan the layout of AnkerPak’s separate packaging facility to maximize utilization of the space in that building. That Woodham lives in the Columbus area (all GaMEP region managers reside in the communities they serve) was a critical difference, Anker said. He saw it as reflective of a deeper commitment toward a partnership.

After he laid out the operational challenges he wanted GaMEP to address, Anker said, the results were immediate. Morning meetings with senior managers at the plant changed and were structured in a way that allowed for more individual accountability and reduced the extra labor costs connected to planning and setting up on the plant floor. “It was more fluid communication,” Anker said, adding that the changes saved money—a tangible result—but they led to other benefits, as well. “The changes in morale led to better productivity. That saved us money and that money is real,” he said. “Because of that relationship we started building with the MEP the barriers were lower and results were higher on my side. It’s a great resource to have—a great university with representatives living and working in the regions they represent.”

‘IT’S A PARTNERSHIP’

Fite, GaMEP’s director, stresses that the organization’s approach is collaborative. “The people in MEP are passionate about serving. Everyone here wants to serve manufacturers and help them grow,” she said. “When we go into companies, we’re not just going there to provide a solution, we want to create a long-term, meaningful relationship. It’s a partnership.”

That’s how Scott Bunn views GaMEP’s work with his company, Groove-Pin Corp. in Newnan, Georgia. The company manufactures threaded inserts, grooves, and engineered fasteners and components.
Bunn, who is operations manager at Groov-Pin, said the company first approached GaMEP about six years ago to incorporate some lean manufacturing processes — methods designed to reduce operational waste.

"They started looking at our issues internally," Bunn said. "Key areas of focus included scheduling, cutting the lead-time between orders, and shipping on time to customers.

"We immediately saw results," Bunn said. "Our on-time performance had been in the 78 to 85 percent range. Just last year, our average on-time performance was 95 percent."

**CHALLENGED TO EXCELLENCE**

From there, Groov-Pin tackled not only the lead time between customers’ orders and actual shipping. The company incorporated a number of practices using the “kaizen” model, which encourages cross-functional teams within companies to look for areas of operational improvement and efficiency.

“Our lead-time was 45 days prior to implementing kaizen. After that, it was in the 20-day range. It was a significant improvement and had a big impact on sales,” Bunn said.

The company also looked at creating more opportunities for staff — particularly those on the shop floor — to discuss their ideas that led to regular brainstorming sessions where employees were encouraged to submit ideas to improve operations.

"It was a way to empower the people on the shop floor. Then's now a microphone for them to get their ideas out," Bunn said. "Staffers now receive a $5 gift card just for submitting an idea and an additional $50 if it is implemented. The company posts all the ideas in the staff break room for visibility."

"We’re starting to do this as well," Bunn said. "That means a lot. It’s not a sales approach; it’s a differentiator, he said. "We have been able to remain competitive by matching pricing with our domestic and offshore competitors."

"We are adopting that as our standard product development project process, and we have other groups within our sector that are starting to do this as well," Bunn added.

"KEEP JOBS IN THE PLANT"

"We’ve come up with some great ideas," Bunn said. "For example, one staff suggestion involved changing the tap welding tray that is placed near each machine to increase efficiencies.

"We were working on a major product with our largest customer, Moog, which also has an engineering office in Kennesaw, Georgia, encourages employees to come up with ideas — such as this organized tools box near each machine — to increase efficiencies.

"They challenged us. No matter what we come up with, they continually say, ‘What can we do that’s better than that?’ They really just broke open the bottlenecks for planning the project."

With time being a critical component, the team also adopted 15-minute standing meetings, which kept members focused on the project, helped them make decisions quickly, and empowered them to take action. The changes freed up project managers to take on more responsibilities, Martin said.

"We are adopting that as our standard product development project process, and we have other groups within our sector that are starting to do this as well,” he added.

WHERE WE ARE
Thermoelectric Generators (Thor-Mô-1-Lek-Trik)

Thermoelectric generators (TEGs) are solid-state devices that convert heat directly to electricity without moving parts. These generators are often made of inorganic semiconducting materials. Georgia Tech researchers are evaluating the use of polymers in TEGs, taking advantage of the material’s flexibility and low thermal conductivity to create TEGs that may be more efficient than conventional devices.