Modern economies depend on it to keep them going. But continued use of fossil fuels like petroleum and coal deplete a limited resource and create both air pollution and global warming concerns.

Researchers at the Georgia Institute of Technology are addressing energy issues on several fronts, advancing renewable energy technology, exploring potential new energy sources and making more efficient use of conventional fossil fuels – while reducing their environmental impact.

Fuel cells that convert chemical energy directly to electrical energy offer tremendous potential for using fuels more efficiently – while reducing emissions. Georgia Tech’s broad-based fuel cell program, coordinated by the Center for Innovative Fuel Cell and Battery Technologies, includes everything from the tiniest micro fuel cells integrated into microelectronic packages all the way up to refrigerator-sized units for powering homes. The program is developing innovations in membranes, fuel reforming, systems integration, catalyst optimization, modeling and other key areas.

Research beneath the ocean floor has implications for both production of conventional fossil fuels and development of a potential new energy source. Gas hydrates are a solid form of methane and water found in sediment deep beneath the ocean floor. Touted as a potential energy source, the gas hydrates are a critical component of the carbon cycle affecting global warming and a potential threat to deep-sea petroleum production.

Atop Georgia Tech’s Aquatic Center – built to house swimming and diving events of the 1996 Summer Olympics – photovoltaic cells produce 30 percent of the building’s electricity, enough to power 70 average homes. Researchers are evaluating the long-term performance of the massive array. They are also advancing basic technology to make photovoltaic cells more efficient and less costly.

Researchers in the National Electric Energy Testing, Research and Applications Center (NEETRAC) are field-testing electric and hybrid-electric vehicles that are beginning to enter the market. Their work helps manufacturers ensure that the new systems meet real-world needs. Finally, engineers with Georgia Tech’s Economic Development Institute are helping Georgia companies use energy more efficiently. They’ve also developed ANSI/MSE 2000, the first management system for energy. The standard is being implemented nationwide.

Energy innovations developed at Georgia Tech will help keep the world’s economy moving. The articles that follow highlight this work.
David Parekh, director of the Center for Innovative Fuel Cell and Battery Technologies, holds a hybrid power source designed and built at the Georgia Tech Research Institute. It provides sustained power from a fuel cell, power storage from a battery and bursts of peak power from a capacitor.
The common denominator for these dreams is a 160-year-old innovation known as the fuel cell. By directly converting chemical energy to electrical energy, fuel cells promise a revolution in transportation, distributed power generation and electronic devices of all types.

As part of an integrated program, focused by the Center for Innovative Fuel Cell and Battery Technologies, Georgia Institute of Technology researchers are advancing a broad range of fuel cell technologies. With support from private corporations and federal agencies, these projects will help turn fuel cell visions into reality – some by the end of this decade.

Already, fuel cells boast a 30-year history of powering space missions. They also now run small numbers of demonstration buses, automobiles and stationary power units. But before fuel cells can compete economically with today’s electrical generation technology, internal combustion engines or even batteries, dramatic improvements must be made in performance and cost.
**Why Fuel Cells?**

First demonstrated in 1839, fuel cells produce electricity by separating the electrons of hydrogen from their protons. In the simplest form, hydrogen gas flows into an electrode (the anode), where a platinum catalyst separates the electrons from the protons. The positively charged protons pass through a membrane into another electrode (the cathode), where a catalyst helps them combine with oxygen to form water. The electrons flow along a collection plate to produce electrical current that can turn motors, power lights or produce heat.

Traditional power plants and engines burn fuel to extract its chemical energy, using hot gases to spin turbines, create steam or move pistons. Multiple conversions from chemical to thermal to mechanical to electrical energy waste power in these “heat engine” systems. But because fuel cells convert chemical energy directly to electrical energy, they can be up to three times as efficient as today’s engines and power plants at extracting power from fuels.

Fuel cells also provide environmental advantages by avoiding combustion pollutants.

Fuel cells running on hydrogen – a potentially renewable fuel – produce only water, heat and electricity. But because hydrogen is inconvenient to store and transport, hydrocarbon fuels – natural gas, methanol, ethanol, gasoline and even diesel – are increasingly being used to power fuel cells, though they also produce carbon dioxide and often require a chemical reforming step. Still, because fuel cells are more efficient than combustion at extracting power, their carbon dioxide emissions are lower per unit of power produced. And nitrogen oxide emissions – a key component of ozone pollution – are near zero.

A single fuel cell generates less than a volt of electricity. To produce useful voltages, multiple cells must be combined into “fuel cell stacks” producing the specific voltages required for an application. This modularity provides another fuel cell advantage.

Along with key support infrastructure, Georgia Tech researchers are currently working on several types of fuel cells.

Because they can use a wide range of fuels with high efficiency, solid oxide fuel cells may be the power source of tomorrow – though they’re too expensive today. Polymer electrolyte membrane (PEM) cells are the choice today for transportation and distributed stationary power, though their robustness still needs improvement. Direct methanol fuel cells, a variation on PEM technology ideal for compact power applications, use liquid methanol, which is easy to transport but currently lacks the efficiency of other cells. Alkaline fuel cells, used primarily in space and military applications, are being considered for specialized commercial segments, while existing products for electric utility applications use primarily phosphoric acid or molten carbonate fuel cells.

**Lowering the Temperature, Lowering the Cost**

Solid oxide fuel cells offer important advantages over other fuel cell technologies, including high efficiency and flexibility to use a range of hydrocarbon fuels without a reforming step. But those advantages come with a cost: Solid oxide fuel cells operate at 800 degrees Celsius, requiring use of expensive ceramic materials or alloys able to withstand the heat. Their operating efficiency suffers dramatically at lower temperatures.

Meilin Liu, a professor in the School of Materials Science and Engineering, is working on electrode technology that will reduce or eliminate the low-temperature efficiency penalty. His group focuses on providing a larger reaction surface area by reducing the size of pores in which reactions take place and through which reactants flow. Increasing the surface area accelerates the electrochemical reactions that produce electricity, and Liu is using that to compensate for the loss of efficiency caused by lowering the temperature. His electrodes operate at 500 degrees C, allowing him to use less costly materials, such as stainless steel, without compromising performance.

“To efficiently release the electrical energy, we need the electrochemical reactions to occur very fast,” he explains. “One way to facilitate the electrochemical reactions is to increase the surface area of the electrode. We can do that by making very fine pores. But if the pore size becomes too small, gas transport into and out of the electrode becomes difficult.”

His “functionally graded” electrodes not only display high catalytic activities for fast electrode reactions, but also have optimum architecture for rapid gas transport, dramatically reducing the internal losses at low temperatures. Beyond cutting materials costs, lowering the temperature could also extend fuel cell life and improve reliability.

Ultimately, Liu sees solid oxide fuel cells powering individual homes, replacing the furnace and hot water heater – and allowing homes to operate apart from the local power grid. “You would get higher efficiency, so you would need less natural gas to produce the same amount of useful energy,” he notes. “The fuel cell would also produce much less pollution compared to a furnace.”
Solid oxide cells can directly use natural gas and methanol. With additional fuel reforming, they can also operate on gasoline or diesel fuel, which could make them ideal for transportation applications, where they would be more efficient than PEM cells.

But there is a long way to go before fuel cells can compete economically, says Liu, who is co-director of the Center for Innovative Fuel Cell and Battery Technologies. The capital cost for solid oxide fuel cells now tops $6,000 per kilowatt, compared to $400 for conventional power plants.

Liu’s lab supports 11 Ph.D. students and seven post-doctoral students or visiting scientists with funding from several corporations and federal agencies, including the National Science Foundation (NSF), National Energy Technology Laboratory (NETL), U.S. Department of Energy (DOE), Defense Advanced Research Projects Agency (DARPA) and the Office of Naval Research (ONR).

**Powering the Electronic Soldier**

Sensors, electronic weapons and communications gear have become vital to soldiers in the field. The technology provides a key advantage, but also comes with a cost: power requirements that are becoming more and more difficult to meet with existing battery technology.

Miniature fuel cells could help meet the power needs of future soldiers, freeing them from the burden of battery packs and chargers, and the problems of spent batteries. Through funding from DARPA, a group of Georgia Tech researchers is developing a 20-watt, low-temperature solid oxide fuel cell based on advanced manufacturing technologies and Liu’s new materials and functionally graded electrodes. The research team includes Joe Cochran, Jim Lee, Meilin Liu, Dave McDowell, and Tom Sanders from the School of Materials Science and Engineering and the Woodruff School of Mechanical Engineering.

Researchers at the Georgia Tech Research Institute (GTRI) are addressing the system engineering issues surrounding compact fuel cells for soldiers and larger systems for transportation and distributed generation. “The fuel cell is more than a magical electrochemical stack that converts fuel to electricity,” notes David Parekh, director of GTRI’s Aerospace, Transportation and Advanced Systems Lab and director of the Center for Innovative Fuel Cell and Battery Technologies. “You also have to provide fuel processing on the front end, and power electronics on the other end to convert direct current to alternating current or to regulate voltages for DC applications. And you have to integrate and manage all the components as a complete system.”

GTRI contributes its long experience with engineering military systems to the initiative. Beyond Parekh, the GTRI fuel cell initiative involves more than a dozen full-time researchers, several technicians and numerous students. Building on Georgia Tech’s broad capabilities, it has developed strategic partnerships with leading private sector producers of fuel cell technology, such as UTC Fuel Cells and Motorola.

“We have developed a symbiotic relationship with Motorola in developing power electronics targeted toward a direct methanol fuel cell the company is developing,” says Allan Williams, a GTRI senior research engineer. “It’s very much a two-way street. We help them develop aspects of their product, and they help us develop components of systems that interest us.”

Parekh’s group also focuses on a unique combination of fuel cells, batteries and capacitors to power small-scale sensing applications. The combination provides the best of all worlds – sustained power from the fuel cell, power storage from the battery and bursts of peak power from the capacitor for transmitting data. Unattended sensors, remote communications devices and unmanned aerial vehicles need such a combination.

“We saw several applications that required not only the ability to deliver power efficiently, but also to deliver large amounts of power instantaneously,” Williams says. “We needed to not only have fuel cells, but also to overcome their inherent limits on delivering large amounts of power without building large cells. By bringing the fuel cell together with the electrochemical capacitor, we were able to meet that need.”

Parekh’s group has also investigated tiny hybrid systems based on as few as one fuel cell and one tiny coin battery that could be optimized based on power and size needs.

In another project, research engineer Gary Gray is working on the problem of properly controlling moisture in PEM fuel cells. “The polymer electrolyte is only conductive when it has a certain amount of water absorbed into it,” he explains. “Water management in this system is really critical because if you let it dry out, the whole stack loses power. But if too much water accumulates, you have trouble getting the hydrogen and oxygen in.”
Gray hopes to develop a novel water and gas flow modulation system based on testing done with a 100-watt fuel cell stack built in GTRI. The system also includes a fuel reforming system that produces hydrogen from methane.

**Micro Fuel Cells Integrated on a Chip**

The smallest part – in physical dimensions – of the Georgia Tech fuel cell program is a project to incorporate a tiny fuel cell into a microelectronic package that would include an integrated circuit and sensor. The system might operate unattended for up to a year, sniffing for dangerous gases or listening for vibrations from approaching vehicles.

The micro fuel cell would operate on a solution of methanol and water, using a unique membrane developed by researchers at Case Western Reserve University.

Integrating all three devices into one package potentially makes fabrication more efficient and allows different components to work together. For instance, air brought in to operate the fuel cell could also cool the integrated circuit and provide the flow for the gas sensor, notes Paul Kohl, a professor in the School of Chemical Engineering. Metal layers deposited for the integrated circuit could also produce the fuel cell electrodes.

But co-fabricating the components on a silicon chip adds to the design challenge. Traditional microelectronics fabrication techniques operate at temperatures that would damage the polymer membrane of the fuel cell. Building air channels small enough goes beyond what is known about small-scale fluid flow. And to avoid using precious electricity for pumping, a micro-scale clock spring may be used to maintain pressure inside the fuel tank.

Beyond the fabrication challenges, Kohl and his team must also overcome limitations in fuel cell efficiency. Because methanol can cross over from the anode to the cathode, existing methanol fuel cells use dilute fuel – which limits power production to as little as two-tenths of a watt in a cell this small. Boosting the methanol concentration would produce more power, or allow use of a smaller fuel tank.

“We have to get all the materials and components to work well together,” Kohl notes. “We also have a multi-dimensional challenge of how to design an efficient cell. There are a lot of trade-offs.”

Sponsored by DARPA, the project also includes Peter Hesketh, a professor in the School of Mechanical Engineering, and Christopher Moore, a graduate student in the School of Chemical Engineering. Beyond the sensor, Kohl hopes the micro fuel cell technology will ultimately have applications in larger equipment such as cellular telephones or laptop computers.

**Cutting Catalyst Cost Through Fractals**

Fuel cell technology works best and pollutes least when powered by pure hydrogen, but hydrogen is inconvenient to transport and store. So there is strong interest in hydrocarbon fuels – such as gasoline or methane – from which hydrogen can be produced through a catalytic reforming process. But the cost of catalytic metals – platinum or palladium – poses a serious obstacle in the drive to make fuel cells economical.

Andrei Fedorov, a professor in the School of Mechanical Engineering, hopes to cut the amount of catalyst needed by as much as 70 percent by putting the particles only where they do the most good.

“Intuition tells you that you want to have the maximum catalytic surface area,” he notes. “But you actually need to have it only at strategic places on the surface. We are placing the catalysts in such a way that we can use much less of the expensive materials while not compromising the reaction chemistry.”

**Center for Innovative Fuel Cell and Battery Technologies**

Georgia Tech’s Center for Innovative Fuel Cell and Battery Technologies pursues a four-part mission: (1) to be a catalyst for developing revolutionary fuel cell and battery technologies, (2) to create partnerships with leading industry and government organizations to advance the technology, (3) to educate industry professionals, university students and budding K-12 scientists, and (4) to serve as a magnet for economic development.

Center Director David Parekh and his colleagues seek to develop a broad suite of key technologies needed to enable major advances for the fuel cell and battery industry. “Companies out of necessity are going to have to freeze the concepts they are bringing to market and focus development narrowly along their product lines,” he notes. “We want to focus longer term on embryonic technologies that could produce broad advances. There are pieces of the technology that all of them will need, whether it’s advanced materials, power electronics, fuel processing or distributed generation protocols. There is a real opportunity for Georgia Tech to develop innovations that could address those needs.”

For more information, you may visit the Center’s Web site at www.fcbt.gatech.edu or contact Parekh at 770-528-7826, or by e-mail at david.parekh@gtri.gatech.edu.
The science of fractals may guide placement of the catalytic particles, an approach Fedorov and his students are studying through computer models and for which they hope to have experimental verification soon. Their placement technique could also help cut the costs of fuel cells themselves, which also use costly catalysts.

With support from Air Products and Chemicals, Inc., Fedorov’s group also explores the unique issues involved in small-scale fuel reforming systems that might be used in laptop computers or cellular telephones. “There is a lot of difference between a large system and a small system in the kinetics of reactions, mitigation of heat transfer and mass transfer,” he says. “There is a lot of room for imaginative solutions here.”

He expects such portable electronics to be an important early application for fuel cells because the disadvantages of their existing power source — batteries — are well known. “Lowering the costs will make fuel cells more attractive than batteries within the next decade, with some applications for fuel cells powering portable electronics available in two or three years,” he predicts.

"As we get into fabricating fuel cells in large volumes, that is going to drive the cost down just like it did with integrated circuits. I believe we will make fuel cells very competitive economically. And that will happen in the next five to 10 years.”

Modeling Guides Experiment

New technologies must ultimately be proven experimentally, but computer models can help researchers choose the most promising path and evaluate options. Which materials would be best for specific conditions? What combination of fuel cell stacks and traditional gas turbines would provide the optimal mix of power and reduced emissions? How will fuel reforming systems, fuel cells and power conditioning systems work together? When should a fuel cell stack be shut down for maintenance?

Bill Wepfer, Comas Haynes and their graduate students work closely with Georgia Tech’s experimental researchers to provide that kind of guidance, using a detailed knowledge of thermodynamics, heat transfer and energy.

“Our models can tell other researchers what properties are needed in new materials, and what kinds of systems will produce what kinds of outputs,” says Wepfer, a professor in the Woodruff School of Mechanical Engineering and chair of the school’s graduate studies department. “Modeling complements prototype testing because once you do the systems tests and calibrate your models, you can use the modeling to tremendously enhance the understanding and save time from routine testing.”

Haynes, a GTRI researcher, is applying unique Lagrangian modeling techniques to study the impact of transients on the electrochemical and thermal characteristics of fuel cells. The modeling gives clues about what might happen under difficult conditions, such as when a generator must shut down suddenly or a load increases rapidly. It can also help predict the useful life of fuel cells by looking at the kinds of materials failures likely to occur and their impact on performance.

The Fuel Cell Road Ahead

With increased funding from Washington and growing corporate investment, fuel cell research and development is accelerating. In California, automobile manufacturers and fuel companies work together to demonstrate transportation uses of fuel cells. Large equipment companies like UTC Fuel Cells and Siemens Westinghouse have already demonstrated stationary fuel cells that operate reliably for five years or more, and many other companies like Motorola, Honeywell and Delphi are investing for their market areas.

How long will it be before we replace the furnace with a fuel cell, drive fuel cell cars or refuel our fuel cell–powered phones instead of recharge them?

“There are fundamental materials science and chemistry discoveries ahead that will lead to the kinds of reductions in cost and improvements in performance that will make fuel cells a reality,” says Wepfer, who has been working on energy systems since the 1970s. “A lot of organizations, both in government and the commercial world, are investing in fuel cells.”

He believes Georgia Tech is uniquely qualified to contribute to fuel cell development because of its broad-based expertise in materials, chemistry and chemical engineering, and manufacturing – all disciplines needed to make key advances.

Meilin Liu expects to see significant commercial use of the technology within a decade, perhaps sooner, thanks to economies of scale.

“As we get into fabricating fuel cells in large volumes, that is going to drive the cost down just like it did with integrated circuits,” he says. “I believe we will make fuel cells very competitive economically. And that will happen in the next five to 10 years.”

For more information, you may contact Meilin Liu, School of Materials Science and Engineering, Georgia Tech, Atlanta, GA 30332-0245. (Telephone: 404-894-6114) (E-mail: meilin.liu@mse.gatech.edu); or David Parekh, Aerospace, Transportation and Advanced Systems Lab, Georgia Tech Research Institute, Atlanta, GA 30332-0800. (Telephone: 770-528-7826) (E-mail: david.parekh@gtri.gatech.edu)

Material on micro fuel cells is based on research sponsored by the Air Force Research Laboratory and DARPA under agreement F33615-01-1-2173. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of Air Force Research Laboratory, DARPA, or the U.S. Government.
Methane gas hydrates are really much more. Indeed, they may contribute to global warming, and could represent a potential threat to deep-sea petroleum production.

At the Georgia Institute of Technology, an interdisciplinary group of researchers studies gas hydrates from all these angles, coordinated by the Focused Research Program on Gas Hydrates. The work includes modeling, sea floor exploration, a novel chemical sensing system for continuous underwater monitoring, biological research and geo-technical studies with laboratory-grown hydrates in sediments.

Methane gas hydrates exist along the continental margins worldwide, most in oceanic sediments hundreds of meters below the sea floor in water depths of more than 500 meters – or in permafrost areas. The U.S. Geological Survey estimates that gas hydrates off the U.S. coast or in Alaskan permafrost could contain 300 times the amount of methane available from conventional reserves. These hydrates exist as disseminated deposits, chunks several centimeters across and sometimes as concentrated layers.

But producing methane from gas hydrates faces some daunting challenges.

“If you could get these hydrates out of the sea floor, you’d have a concentrated form of natural gas,” says Carolyn Ruppel, associate professor of geophysics in Georgia Tech’s School of Earth and Atmospheric Sciences and coordinator of the gas hydrate program. “But a key question is whether it would take more energy to extract the gas hydrates than the gas may provide.”

Aside from the difficulty of deep-sea operations, mining the hydrates could destabilize the ocean floor or even trigger the runaway destabilization of the hydrates. The methane might be tapped by pumping heated liquid into the
hydrate deposits to dissociate and recover the gas, but this would be an energy-intensive operation. Another alternative would be to drill through the hydrate layers into pools of free gas below – a potential hazard.

And methane production presumes the ability to identify large hydrate deposits – something scientists are only now discovering. As part of a National Oceanic and Atmospheric Administration (NOAA)-sponsored multi-university research team aboard the RV Atlantis last autumn, Ruppel helped explore an area off the South Carolina coast known as the Blake Ridge. There, researchers found hydrates just above the ocean floor and filmed the formation of a hydrate cluster from a methane bubble. Through such explorations, scientists hope to learn more about where to find deposits of gas hydrates – without widespread drilling.

And methane production presumes the ability to identify large hydrate deposits – something scientists are only now discovering. As part of a National Oceanic and Atmospheric Administration (NOAA)-sponsored multi-university research team aboard the RV Atlantis last autumn, Ruppel helped explore an area off the South Carolina coast known as the Blake Ridge. There, researchers found hydrates just above the ocean floor and filmed the formation of a hydrate cluster from a methane bubble. Through such explorations, scientists hope to learn more about where to find deposits of gas hydrates – without widespread drilling.

Later this year, Ruppel – along with Assistant Professor Daniel Lizarralde from the School of Earth and Atmospheric Sciences and colleagues from Rice University and Scripps Institute of Oceanography – will explore hydrates in the Gulf of Mexico as part of a project sponsored by the National Science Foundation.

“We will be trying to measure heat, the volume of methane coming out, and the rate that fluid is flowing from the sea floor,” she explains.

Research Horizons

Researchers (l-r) Neil Pennington, Manfred Karlowatz and Boris Mizaikoff re-align optical components and the fiber optic sensor head of the S.C.U.B.A. system. The device can operate deep in the ocean to detect and measure a wide range of hydrocarbons and chlorinated hydrocarbons.

“If you are drilling into the gas hydrate, you have to worry that the hydrate could suddenly dissociate, leading to the collapse of the sediment supporting the drill stem.”

Continuous Chemical Monitoring Underwater

Boris Mizaikoff specializes in underwater optical sensing. An assistant professor in the School of Chemistry and Biochemistry, he and his colleagues have developed a compact sensing system able to continuously measure organic compounds deep beneath the ocean surface.

Known as Spectroscopy using Chemical sensors for Undersea Based Applications (S.C.U.B.A.), the system uses a chemically modified fiber-optic sensor connected to a Fourier transform infrared (FTIR) spectrometer – operating within a cylindrical pressure vessel less than a meter long. The special polymer coating on the optical fiber reversibly absorbs organic compounds from the water. An infrared light source excites the absorbed molecules via the evanescent field guided outside the fiber, whose absorptions are analyzed by the FTIR. This produces qualitative and quantitative measures of compounds present.

“Rather than taking a sample, bringing it to the lab and putting it into a spectrometer, we want to bring the measurement device to the sample so we can do in-situ analysis,” Mizaikoff explains. “That allows us to do these measurements continuously and under fairly harsh conditions.”

S.C.U.B.A. has already shown its ability to measure a range of organic compounds, including hydrocarbons and chlorinated hydrocarbons. With support from the U.S. Department of Energy through the University of Mississippi, Mizaikoff and his colleagues are developing an optical sensor system that will allow accurate methane measurement.

Growing and Studying Hydrates in the Lab

Scientists lack a clear understanding of how gas hydrates form in sediments – and how their formation affects the stability of the ocean floor. Carlos Santamarina, a professor in the School of Civil and Environmental Engineering, hopes to provide answers by growing gas hydrates in “dirty systems,” that is, at mineral surfaces and within different types of soils.

In a process he compares to medical diagnosis, Santamarina and his colleagues use electromagnetic and elastic waves to monitor hydrate growth, studying the formation process to learn about its effects on sediment response. Instead of
methane – which forms hydrates in sediments very slowly – they grow the icy structures from tetrahydrofuran (THF) so they can reproduce the very lengthy natural hydrate formation in shorter laboratory time. In addition, they study the formation of hydrate monolayers on minerals using atomic force microscopy.

Hydrate deposits in sea floor sediments may form “lenses,” like water forms ice layers in the soil during the winter months in northern states. In spring, if the ice melts faster than the water can dissipate, the soil becomes unstable and can cause extensive damage to highways. “If methane hydrates form these lenses under the sea floor and become destabilized for whatever reason – petroleum production or climatic change – we could have massive landslides on the sea floor,” he says.

A Concern for Drilling, Climate Change

While the value of gas hydrates as a future energy resource remains uncertain, the hazards they pose to production of conventional energy are clear. Oil companies are running out of reserves in shallow waters, forcing them to operate in areas where they may drill through hydrate formations. While they may eventually be able to produce energy from these hydrates, the more immediate concern is the potential hazards that gas hydrates may pose for oil drilling.

“If you are drilling into the gas hydrate, you have to worry that the hydrate could suddenly dissociate, leading to collapse of the sediment supporting the drill stem,” Ruppel says.

Perturbations of the sea floor can produce still bigger problems. Major sea floor slides can cause tsunamis, large oceanic waves that bring catastrophic damage to low-lying coastal areas. Beyond energy interests, methane gas hydrates may also play a role in global warming. Even slight warming could free significant amounts of methane, a potent greenhouse gas.

“You’d have to warm the deep ocean waters by just a few degrees,” Ruppel notes. “There is a time delay built into the system, so it would take quite a while for the sediments to heat up. But if even a portion of the methane released from hydrates gets out of the oceans and into the atmosphere, it could exacerbate global warming and lead to a synergy between destruction of hydrates, release of methane and climate change.”

As an alternative source of energy, a hazard to conventional energy production and a global warming concern, “burning ice” is indeed a contradiction. RH

For more information, please contact Carolyn Ruppel, School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA 30332-0340. (Telephone: 404-894-0231) (E-mail: cdr@piedmont.eas.gatech.edu) Or visit http://hydrate.eas.gatech.edu/gthydrates/

Above: This map, modified from one published by the U.S. Geological Survey, shows the distribution of known gas hydrate deposits.

Below: An artificially-colored gas hydrate crystal synthesized in the lab of Carlos Santamarina shows its crystalline structure.

Left: Researchers retrieve a core sample containing gas hydrates taken from a site off the South Carolina coast.

This publication on the S.C.U.B.A. system was made possible through support provided by the U.S. Department of Energy through the University of Mississippi under the terms of Agreement/Contract No. DE-FC26-00NT40920. The opinions expressed herein are those of the authors and do not necessarily represent views of the Department of Energy or the University of Mississippi.
While researchers work to improve renewable energy sources such as photovoltaics and explore alternative technologies such as fuel cells, Bill Meffert is focused on immediate assistance to Georgia companies with energy-related concerns.

Meffert, manager of the energy and environmental services group for Georgia Tech’s Economic Development Institute (EDI), says that although new technologies will ultimately impact energy sources, companies are more interested now in reducing the cost of using current energy sources.

EDI assists companies in two ways: plant-wide assessments and specific technical assists. In a plant-wide assessment, the entire energy system of a facility is analyzed for possible savings. Meffert’s group performs 30 to 35 plant-wide assessments a year.

“We follow what I call a priority pyramid,” Meffert says. “The first thing we look for is how the company purchases energy — looking at rates and purchasing practices to figure out the most advantageous procurement strategy. Then we look at operations and maintenance opportunities. These opportunities are less costly to implement but can give a quick payback, such as checking steam traps, finding air leaks, repairing controls and so forth.

The third category is capital opportunities, and those require significant dollars to implement. You...
can achieve a lot of savings, but they’re also riskier because you’re spending significantly more money to bring about efficiency gains.”

Technical assists focus on specific systems a company wants analyzed, such as compressed air, steam or motor drives. These assists are much less time-intensive for Meffert’s group, which usually spends two or three engineering days on each project.

In its 25 years of existence, the energy and environmental services group has weathered many changes and seen new trends develop in the field of energy. After the 1970s, energy costs decreased to the point that, according to Meffert, “nobody paid any attention to energy.” That’s when Georgia Tech’s EDI got involved in pollution prevention and energy management opportunities.

Today’s hot button topic for energy specialists is deregulation and fuel price volatility, which has introduced a degree of uncertainty for Georgia companies.

“Fuel prices have gotten very volatile,” Meffert notes. “The average costs for electricity or gas haven’t increased that much, but the swings can be really devastating to companies.”

Deregulation will continue to evolve, Meffert says, and Georgia’s utilities will continue to change to meet this new, competitive environment.

In addition to providing technical assists, the energy and environmental services group has developed the Management System for Energy 2000 for the American National Standards Institute (ANSI/MSE 2000). The approach is revolutionary, Meffert says.

“This is the first time companies have applied a world-class management system to energy,” he notes. “In the past everyone thought energy management was a technological solution. It requires constant vigilance, and this standard really helps companies put a system in place where they can continue to monitor energy management.”

By working with the U.S. Department of Energy and the Georgia Environmental Partnership, Meffert’s energy and environmental services group has aided an estimated 2,000 companies in the past 25 years. In addition to employing eight full-time energy professionals, EDI uses students from Georgia Tech’s Woodruff School of Mechanical Engineering. Led by Professor Sam Shelton, students gain real-world experience by conducting on-site visits, collecting data and preparing reports.

One company that EDI has assisted is the Genuine Parts Company, a distributor of automotive and industrial replacement parts for companies such as NAPA and iMotion Industries. When the Atlanta-based company experienced a 10 percent increase in light, water and heat expenses in 2001, the president requested that energy-saving measures be explored. The company’s staff researched potential energy consultants and decided that Georgia Tech’s EDI could provide answers and confidence.

EDI’s energy specialists provided strategies for smart energy purchasing and informed management about electrical and natural gas deregulation issues. They also helped the firm with outsourcing management of utility data, bill payment and rate analysis. Overall, this assistance enabled the firm to develop a sound strategy and solutions, and estimated savings are projected between 3 to 5 percent of Genuine Parts’ annual energy expenditures.

With 1,800 locations and 31,000 employees in the United States, Canada and Mexico, Genuine Parts Company generated $8.2 billion in 2001 revenues.

For more information, you may contact Bill Meffert, Economic Development Institute, Georgia Tech, Atlanta, GA 30332-0640. (Telephone: 404-894-3844) (E-mail: bill.meffert@edi.gatech.edu)
As the summer sun rises over Atlanta, it begins converting nitrogen oxides and hydrocarbon compounds — the leftovers of electricity generation and vehicle operation — into ground-level ozone. It’s the beginning of another bad air day for Atlanta.

But as the sun rises over the Aquatic Center at the Georgia Institute of Technology, it initiates an entirely different process. Photovoltaic cells covering the structure’s roof — 342 kW of them — begin producing electricity, enough to provide 30 percent of the building’s power needs — an amount sufficient to energize 70 average homes.

Built to house swimming and diving events at the 1996 Summer Olympics, the Aquatic Center now serves as a test bed for large-scale photovoltaic (PV) arrays. In the past six years, the facility has produced more than 2 billion watt hours of electrical energy — and a wealth of information about the reliability of large PV systems, how they should be connected to the utility grid and what architects should expect from the growing number of similar systems being integrated into new buildings.

“To see such a large system operating on campus every day and performing very close to what we had predicted is very heartening,” says Ajeet Rohatgi, director of Georgia Tech’s University Center of Excellence for Photovoltaics Research and Education (UCEP), operator of the array. “Based on the data we have collected, we are developing better models to predict the performance and reliability of this system over its projected 30-year life.”

Beyond data on reliability and power output, researchers monitoring the system have also noted some factors that hadn’t been figured into their initial predictions, such as the impact of the roof’s curvature. That new knowledge will help designers of future systems improve their performance predictions.

Operationally, the facility has seen near-flawless performance from the PV panels and the electronic equipment that controls the system’s interaction with the external power grid. But Rohatgi notes a few glitches in the power inverters...
— electronic devices used to convert direct current (DC) from the 2,856 panels to AC power.

Researchers have also obtained data from a separate PV system built into a canopy over the nearby Student Athletic Center entrance. That system uses an alternative design, integrating inverters into each panel.

As the demonstration projects produce valuable information about operating PV systems, work under way in UCEP’s labs produces advances in basic PV technology. UCEP researchers work to improve the efficiency of photovoltaic cells, lower their cost and devise more easily manufactured designs — part of efforts to make PV-generated electricity more competitive with other sources.

Photovoltaic cells, mostly based on silicon, absorb light energy from the sun. That boosts the energy level of electrons in the semiconductor material, freeing them to move about in the crystalline structure and produce a flow of electrical current. The percentage of light energy converted to electrical energy provides a measure of the efficiency of different PV cell designs.

“The goal is to get very high efficiencies while keeping production costs low,” explains Christiana Honsberg, associate professor in the School of Electrical and Computer Engineering and a UCEP researcher. “We do this by using novel techniques and clever designs.”

UCEP researchers have begun evaluating one such clever design: building cells on low-quality thin multi-crystalline silicon material that costs just a third as much as the material normally used.

They have developed a single silicon nitride processing step that simultaneously anneals the cells, applies an anti-reflection coating — and introduces hydrogen atoms to passivate defects in the lower-quality silicon. The resulting cells are nearly as efficient as those produced with higher-cost materials.

UCEP researchers have pioneered rapid thermal processing of silicon cells and have made cells with record-high efficiencies. They are also developing a rapid processing system that uses a continuous belt line to move cells through a high-temperature furnace. This technique may trim production costs by cutting diffusion time from two hours to as little as six minutes.

And they are pushing established limits on the thickness of cells — with thinner devices more forgiving of defects. The goal, notes Rohatgi, is to reduce the cost of PV through technology development and efficiency improvement.

“We are working on several approaches at the same time,” he says. “If we can start with low-cost silicon, that holds down materials costs. If we can use rapid processing technologies, that reduces the processing cost and time. And if we can improve efficiency, that reduces the size of the entire PV module, which has an additional impact on the cost of the entire assembly or system. This way we can make PV competitive with the traditional energy sources.”

Efficiency remains the goal of PV cell research. Most cells mass-produced today are just 12-15 percent efficient, while the best laboratory-produced silicon cells have efficiencies as high as 24 percent. An industry goal is to close that gap, increasing efficiency of manufactured silicon cells to 18-20 percent over the next 3-10 years by adopting innovations produced by UCEP and other research labs.

Beyond the research efforts aimed at efficiency and cost, Honsberg notes another key factor. As more architects incorporate PV arrays into new buildings, they increase the volume of cell production, creating economies of scale that will help drive down costs much like high-volume computer chips did before them.

Formed in 1992, UCEP now involves three faculty members, five full-time research professionals and ten PhD students. Funding comes from such agencies as the National Renewable Energy Laboratory and the Department of Energy. UCEP researchers also collaborate with leading PV companies such BP Solar, Evergreen Solar and ASE Americas, Inc.

Rohatgi sees a bright future ahead for the program and PV industry.

“As the cost of PV continues to come down, a lot more applications will become favorable. We are doing our part here to make that happen.”

For more information, you may contact Ajeet Rohatgi, School of Electrical and Computer Engineering, Georgia Tech, Atlanta, GA 30332-0250. (Telephone: 404-894-7692) (E-mail: ajeet.rohatgi@ece.gatech.edu)
Vehicles powered by fuel cells promise dramatic efficiency improvements and emission reductions – in the future. But electric and hybrid gasoline-electric vehicles are delivering on those promises today.

At Georgia Tech’s National Electric Energy Testing, Research and Applications Center (NEETRAC), researchers field-test a wide range of vehicle systems, from a hybrid “trouble truck” for utility companies to battery rapid-charging techniques for airline tow tractors to a hybrid version of the popular Ford Explorer. The work helps ensure that when these systems are introduced, they’ll meet real-world needs.

Beyond vehicles, NEETRAC studies other electric power issues, including how fuel cells, photovoltaics and other distributed generation systems will integrate into the electric power grid.

“We do field testing and some integration work on prototype vehicles,” says Caryn Riley, who works in NEETRAC’s Electric & Hybrid Vehicle Research Center. “We have done everything from data acquisition on a golf course to determine the suitability of all-electric carts up to field trials of electric buses.”

Three recent projects are typical:

- As part of a Defense Advanced Research Projects Agency (DARPA) initiative, NEETRAC evaluated a new battery rapid charging system for electric baggage tractors used by Delta Air Lines. NEETRAC worked with the manufacturer on a battery-pack redesign and a ventilation system to prevent overheating. A year-long trial found no evidence of adverse effects on the batteries from the rapid-charging, which allows the tractors to be used 14 hours a day instead of just eight.

- Utility companies now use diesel-powered “trouble trucks” to repair fallen lines and make other neighborhood repairs. The truck engines must now run continuously to provide power for the operator’s bucket and power tools, creating noise and emission concerns. NEETRAC is evaluating a hybrid diesel-electric trouble truck that would operate on its batteries while working in neighborhoods. In the project – which is sponsored by the U.S. Department of Transportation – the batteries would be recharged from the truck’s engine while en-route to the next job, or from the electric power grid at the end of the day’s work.

- Though automobile manufacturers Honda and Toyota already have hybrid gasoline-electric automobiles on the market, larger vehicles aren’t yet available. As part of the national FutureTruck competition, NEETRAC researchers are advising a team of Georgia Tech students that is converting a Ford Explorer to hybrid power. The team chose to build a parallel system in which a reduced-size gasoline engine powers the rear wheels while an electric motor powers the front. The goal is to improve fuel efficiency by 25 percent and cut emissions enough to meet strict California limits – while maintaining all of the Explorer’s standard capabilities. The competition helps the students learn more about hybrid vehicle issues, building a future generation of engineers with these key skills.
NEETRAC also works on issues involving distributed electrical generation made possible by the growing use of fuel cell, wind and photovoltaic systems. Power “back-feeding” from such systems can complicate management of the electric distribution grid by introducing power that may not have the same characteristics as the rest of the grid.

“Utility providers want to ensure the reliability of their service network,” Riley says. “When distributed generation systems are added to this network, a main concern is that any local disturbances in the distributed generation not affect the wider network. How the utility providers and distributed generation producers are dealing with this is an interesting part of the energy market.”

Supported by electric, telecommunications and other utility firms, NEETRAC helps ensure the resolution of such technical issues through real-world testing.

For more information, you may contact Caryn Riley, School of Electrical and Computer Engineering, Georgia Tech, Atlanta, GA 30332-0250. (Telephone: 404-385-0179) (E-mail: caryn.riley@ece.gatech.edu)

Above: Andrew Chriss reviews a drawing of a proposed fuel tank mounting system. Right: Caryn Riley and Jason Parsons make measurements for a new exhaust system to be used in the FutureTruck 2002 platform.