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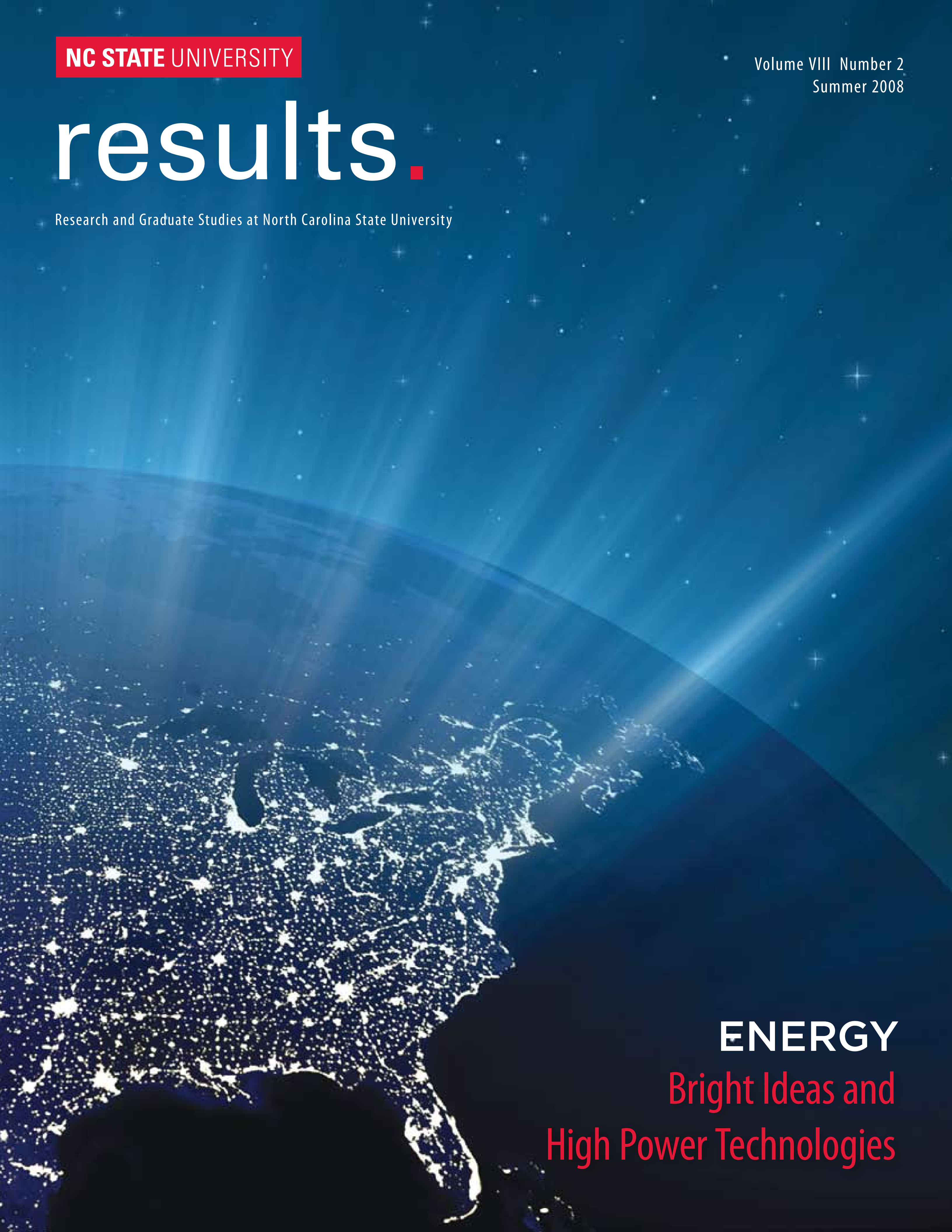
# results.

Research and Graduate Studies at North Carolina State University



## ENERGY

## Bright Ideas and High Power Technologies

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# 'Year of Energy' Revs Up Research, Conservation

Gasoline selling for $4 a gallon. Instability in the Middle East and industrialization in China impacting oil imports. Greenhouse gas emissions accelerating climate change. This perfect storm of energy-related concerns led Chancellor James L. Oblinger to declare 2008 "The Year of Energy" at NC State University.

The chancellor's move reiterated the University's commitment to energy research and placed a new focus on energy use on campus. "Balancing North Carolina's energy security in the 21st century with economic growth and environmental sustainability will require technological breakthroughs in multiple areas, closely coupled with realistic economic analyses and acceptable social policy changes," Oblinger says. "The breadth and depth of energy research expertise and partnerships at NC State gives the University a special responsibility to be fully involved with energy issues."

Oblinger began the Year of Energy by flipping the switch on one of North Carolina's largest solar arrays, developed through an innovative public-private partnership and now providing power to the local electric grid. He also signed the University Presidents' Climate Commitment to address the global warming challenge by modeling ways to eliminate carbon dioxide emissions and integrating sustainability in curricula. Calling on the entire campus to heighten its energy consciousness, he issued a "Million Dollar Challenge" to the 35,000 students, faculty, and staff each to conserve 15 cents worth of energy and water every day, aiming to save more than $1 million a year in campus energy costs.

Energy was the theme of NC State's 2008 Institute of Emerging Issues forum in February, bringing together academic, industry, and government leaders to build a plan for North Carolina's energy future, developing specific action items to provide secure, reliable, affordable, and sustainable energy sources while promoting economic development. Keynote speaker and NC State alumnus Dr. Rajendra Pachauri, who shared the 2007 Nobel Peace Prize with former Vice President Al Gore, provided the research-based outlook of the U.N. Intergovernmental Panel on Climate Change on "a crisis of global proportions."

> "Over the next 50 years, the issues of energy are going to become more complex and more difficult to solve."

The NC State Energy Council, a working group of faculty and staff, now strives to enhance energy research, academic resources, and awareness. "Over the next 50 years, the issues of energy are going to become more complex and more difficult to solve," says Dr. William Winner, Energy Council coordinator. "We must step up our efforts to rethink the way energy is produced, distributed, and used." Since the council was established, the University has adopted the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) silver standard for all new construction. It has also become a partner in the EPA Energy Star program, an energy-efficient products and practices strategy that measures current energy performance, sets goals, and rewards improvements. From initial installations



Plug-in hybrid vehicles (top left) were among the demonstrations of energy conservation on display on the Brickyard during NC State's Energy Fair in January.

Chancellor James L. Oblinger (above) discusses the need for more innovative approaches to energy production and conservation, such as the public-private partnership that led to the implementation of one of the state's largest solar energy arrays (right) linked to the electrical grid.

of efficient LED lights in campus buildings and parking garages to use of natural gas instead of oil for steam and chilled water generation to pumping biodiesel into fleet vehicles and Wolfline buses, energy-saving strategies are being adopted across the campus. NC State's goal is a 20 percent reduction in campus energy consumption over a 10-year period.

> "The breadth and depth of energy-related expertise at NC State gives the University a special responsibility to be fully involved with energy issues."

While walking the energy conservation talk is essential, forging research partnerships is likely to make the biggest difference in the energy picture of the state and nation. By mid-year, NC State had been awarded 86 new grants with an anticipated total value of \$19.3 million. \$64.3 million in new energy proposals is awaiting agency funding decisions. In September, the National Science Foundation announced NC State's biggest Year of Energy success to date—an \$18.5 million award for an Engineering Research Center for Future Renewable Electric Energy Delivery and Management Systems (see story on page 7). "We have a strong reputation in solar, nuclear, and hydrogen technologies, biofuels, and climate change, as well as energy conservation, storage, transmission, and public policy," says Interim Vice Chancellor for Research and Graduate Studies Terri L. Lomax. "But there's no question that 2008 will be NC State's biggest year ever for energy research. Our faculty and students have really stepped up."

Led by College of Physical and Mathematical Sciences Associate Dean Chris Gould, NC State also joined forces with Duke, UNC-Chapel Hill, and research and consulting firm RTI International to form the Research Triangle Energy Consortium, which uses its combined research strengths to address energy problems. In other key partnerships, Duke Energy and Progress Energy have each endowed named professorships and new energy research programs at NC State, supplementing several other new energy-related faculty positions supported by the North Carolina General Assembly.

"Our state is an importer of energy at a cost of about \$16 billion per year," Oblinger says. "Reversing that equation even a little bit would be a long-term economic driver for the state. NC State will provide significant leadership in this high-priority area."

This issue of RESULTS focuses on some of NC State's latest energy research. For more energy stories, see our Summer 2006 issue at http://www.ncsu.edu/research/results/past.html.

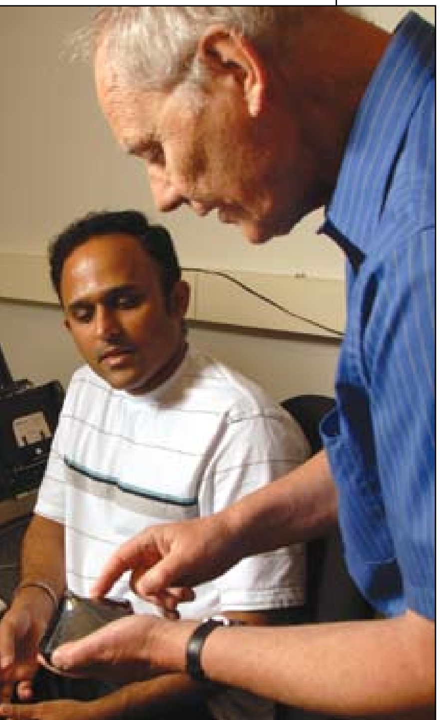
# New Designs and QC Light Up Solar Cells

Graduate student Oliver Luen (background) processes multi-junction solar cells developed by researchers Salah Bedair and Nadia El-Masry.

**In a field west of the NC State campus, a large array of solar panels looks up toward the sun. If it catches enough rays, the array can generate power for seven or eight households.** Still, University researchers believe design improvements can juice these and other solar panels to double—or even triple—the amount of electricity they produce.

The husband-wife research team of Drs. Salah Bedair and Nadia El-Masry, along with electrical engineering professor John Hauser, has already devised solar cells that have the potential to operate at more than twice the efficiency of other photovoltaic devices—40 percent versus 18 to 19 percent. With a three-year grant from the Department of Energy, they aim to raise the bar even further, to about 50 percent efficiency. Their secret is the multi-junction solar cell, a Dagwood sandwich-type device where layers of light-absorbing circuits are stacked atop one another. The researchers are now working to add a fourth layer to the device. "The more we can stack, the better," says Bedair, a professor of electrical engineering. "But there are limitations to the materials."

Dr. George Rozgonyi (right) discusses the characteristics of silicon with Ph.D. candidate Jay Bharathan.



Improving the quality of materials in solar cells will lead to better performance and more energy.

Each layer consists of a film of indium gallium arsenide (InGaAs). Tweaking the relative concentration of the three constituent elements allows the films to absorb different wavelengths of light. The three layers on the team's current solar cells take in the blue and green end of the spectrum, Bedair says, and they hope the fourth layer can pick up more on the red and infrared end. But the stacking and the tweaking alter the crystalline structure of InGaAs, says El-Masry, a professor of materials engineering. So researchers must work at producing crystals with as few defects as possible since defects hinder the process of converting light energy to electricity. "There's really no limit to the multi-junction concept," she says, "if you know how to put it together."

In the multi-junction solar cell, layers of light-absorbing circuits are stacked atop one another in a Dagwood sandwich-type device.

Reducing defects is also the goal of the Silicon Solar Consortium (SiSoC), a materials and processing research center led by NC State and funded by 14 member companies and the National Science Foundation. Researchers use advanced instrumentation to measure the structural, chemical, and electrical behavior of silicon-based solar cells, checking for defects and impurities that can degrade performance, says SiSoC Director George Rozgonyi, a professor of materials science and engineering. "We work with leading-edge companies to optimize crystal growth and device processing," Rozgonyi says. "Solutions to problems often lie in applying fundamental materials science concepts to improving the quality of materials in solar cells, leading to better performance and more energy generation."

# Erasing Millions of Carbon Footprints

**Distinguished University Professor of Electrical Engineering B. Jayant "Jay" Baliga is leaving a huge mark on the world through the tiniest of footprints.** His energy-saving inventions have left him with what many consider to be the world's smallest carbon footprint—the amount of carbon dioxide and other greenhouse gases emitted by a person's activity each year.

The energy savings from Dr. Jay Baliga's inventions offsets the carbon dioxide emissions of about 31.8 million Americans each year.

Baliga launched a revolution in efficient energy use in 1980 with the invention of the insulated-gate bipolar transistor (IGBT), a semiconductor that controls the flow of power in consumer, industrial, and transportation applications. Reducing energy losses by incorporating high-speed switching, the IGBT improves energy efficiency by more than 40 percent in products from cars to appliances to light bulbs and heat pumps. The savings each year through the use of IGBTs in electric motors and compact fluorescent light bulbs alone equals more than 500 billion kilowatt-hours, which amounts to cutting annual carbon dioxide emissions by more than 1 trillion pounds.

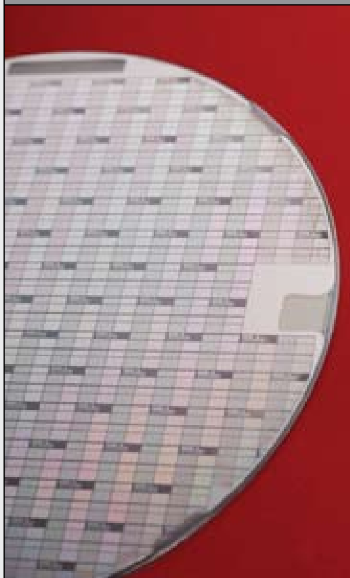
More recently, Baliga invented power semiconductors for use in cell phone towers and laptop computers. Like the IGBT, the more efficient devices save tremendous amounts of power and further cut carbon dioxide emissions. Considering that the average American has a footprint of 44,000 pounds of carbon dioxide annually, the energy savings from Baliga's work offsets the impact of about 31.8 million Americans—more than 10 percent of the nation—every year. Saving all those kilowatt-hours also means utilities and their customers don't have to spend $2 billion for each coal-fired power plant required to meet higher demand for electricity. "I don't like the term 'smallest carbon footprint' because it suggests I have one," he says with a laugh. "I think of it as an enormous negative footprint."

Baliga's carbon offset number could soon increase again as another of his inventions, a silicon carbide semiconductor that is hundreds of times more efficient than the IGBT, is beginning to appear in consumer products. Intellectual curiosity prompted him to predict decades ago that such devices would eventually improve upon silicon transistors. But he says he was often derided as "Chicken Little" because no one saw the need to improve electrical efficiency. "It's satisfying that the world has finally come around to appreciate the benefits of decreased greenhouse gas emissions and increased efficiency," he says.

The next generation of improvements will come from silicon carbide and gallium nitride devices, known as wide bandgap semiconductors, Baliga says. In theory, these devices can handle high-power applications like hybrid cars and the electrical grid with a reduction in power loss of up to 100 times that of silicon IGBTs. "People around the world are not going to stop turning on the light or using a clothes dryer to save energy," he says. "By continually improving efficiency, we can engineer sustainable solutions."

Dr. B. Jayant "Jay" Baliga owns 120 patents on devices that improve the efficiency of electrical and electronic products, from motors and appliances to computers and cell phones.

The insulated-gate bipolar transistors that comprise the semiconductor wafer below were Baliga's first breakthrough in conserving electricity.



# Public Policy Questions Part of Energy Equation


From the field to the fuel pump, the surge in ethanol production has changed the economics for corn farmers and consumers.

**Skyrocketing fuel prices and growing concern over greenhouse-gas emissions have the U.S. scrambling for answers to its energy questions.** But the mad dash for alternatives sometimes produces unintended consequences or leaves public input in the dust, according to NC State researchers, who say the nation's energy policy needs to be more deliberate.

"Given half a chance, the public can develop a working grasp of science and make contributions to the (energy) discussion."

The U.S. has mandated production of 9 billion gallons of biofuel this year—primarily corn-based ethanol—and the law requires 15 billion gallons by 2015. The move is redirecting billions of bushels of corn from the food supply to the energy pipeline and has been one of the primary factors behind soaring food prices. "The mistake we made with corn ethanol was to do too much too fast," says Kelly Zering, associate professor of agricultural and resource economics. "We didn't evaluate the costs of using crops for biofuels." Zering and Henry Tsai, a financial analyst for the North Carolina Solar Center, are now doing just such a study.

Other energy policy moves have produced side-effects as well, says Zering, who also is studying how to make various technologies commercially viable. He cites a 30-year-old tax credit for blending ethanol into gasoline that remains in effect despite the surge in the ethanol market that has made it unnecessary. Such efforts need to be examined more on the front end as the U.S. tries to encourage the production and use of alternative fuels, he says. "How do you design incentives to avoid doing damage to the rest of the economy?"

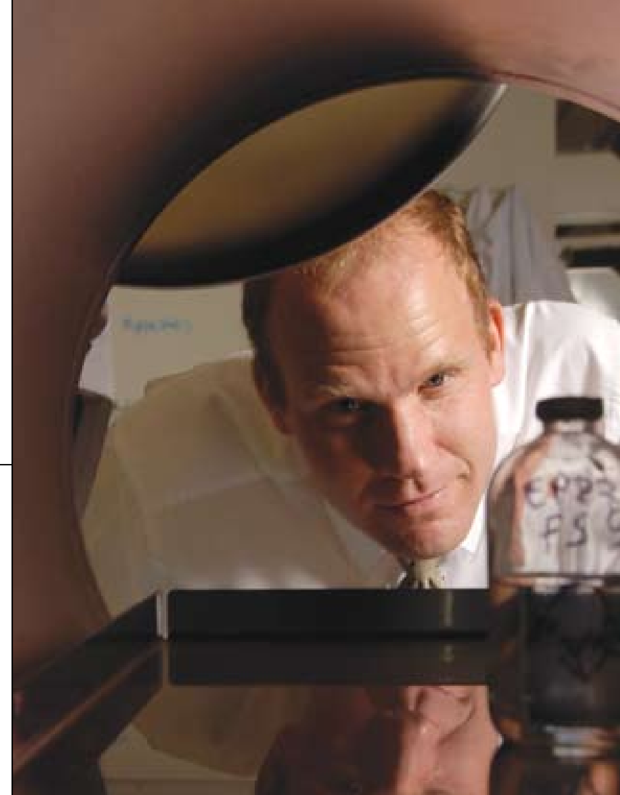
Public input could help the government and the energy industry design a successful policy, suggests Dr. William Kinsella, an associate professor of communication in the College of Humanities and Social Sciences. A former physicist, he is studying the public discussion of nuclear energy production in the U.S. "Given half a chance," he says, "the public can develop a working grasp of science and make contributions to the discussion."

"The mistake we made with corn ethanol was to do too much too fast."

Kinsella previously examined the public's interaction with military and technical experts regarding the ongoing clean-up of nuclear wastes at the Hanford weapons site in Washington state. He is now expanding that research to look at the dynamics in the debate over commercial nuclear power, which is receiving renewed consideration in the U.S. The government invested more than $300 million last year in nuclear energy technology, and utilities are looking at building the first wave of new reactors in more than three decades. "There is no silver bullet in devising public policy," Kinsella says. "But you need to bring citizens and experts together repeatedly over time to make the process work smoothly."

The U.S. government invested more than $300 million in nuclear energy technologies in 2007, and utilities are looking to build the first wave of new reactors in decades.

# Storage Key to Energy on Demand



Dr. Wesley Henderson peers through the antechamber of a glove box at a bottle of ionic liquid, or liquid salt—used in his battery electrolyte research. The electrolyte is the portion of the battery that transports ions between the electrodes where electrochemical reactions occur.

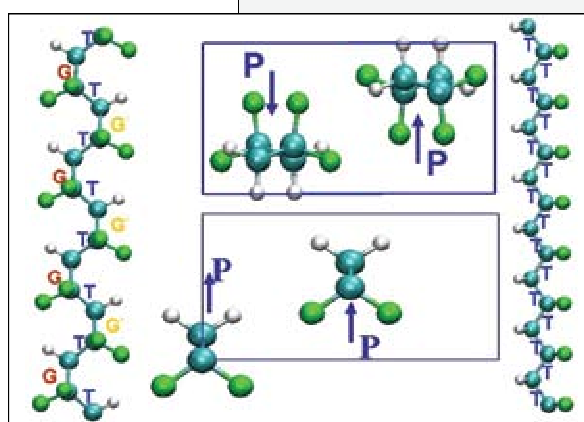
**Dr. Wesley Henderson was in the Iraqi desert in the early 1990s when he experienced an epiphany, realizing his life's work would be in energy research.** "I really thought a lot about what energy independence and the use of alternative fuels would mean to the U.S.," says Henderson, who served as a Private First Class in the Army during the Gulf War and is now an assistant professor of chemical engineering. He is among several NC State researchers trying to build better storage options, such as batteries and capacitors, to prevent generated energy from being lost when not immediately used.

"There are many ways of storing electricity, but our research will allow devices to store more than ever before."

Henderson's research focuses on ionic liquids, organic salts with complex structures and relatively low melting points. Using such liquids as electrolytes in heavy-duty applications like vehicle batteries would provide longer life and improved safety, he says, because they are less volatile at higher operating temperatures than the solvents now used. But ionic liquids are more viscous than other solvents, which limits their conductivity—and battery power. So, the Army Research Office is funding Henderson to find ways to boost the liquids' transport properties without sacrificing their safety benefits.

Henderson is testing various additives that exhibit properties of both ionic liquids and conventional solvents. "We're trying to design molecules that are somewhere in between," he says. "We want to produce an electrolyte that's both highly conductive and stable because, as we move toward plug-in hybrid and fully electric vehicles, we need to revolutionize battery chemistries."

Physics professors Marco Buongiorno-Nardelli and Jerry Bernholc, post-doctoral researcher Vivek Ranjan, and graduate student Liping Yu believe they have found another revolutionary way to boost energy storage. Working with scientists at Penn State, they have shown in supercomputer simulations that a chemical additive boosts the storage capacity of polyvinylidene fluoride (PVDF) polymer capacitors by up to seven times, which could improve the performance of hybrid cars, lasers, and other devices.



This diagram shows the difference between polarized and non-polarized PVDF molecules. The non-polarized molecules (top box) produce the polymer chain on the left, while the chain on the right is produced by the polarized molecules (bottom box).

Capacitors rely on a polarized electric field to store power and release it quickly. PVDF normally provides little energy storage, but adding chlorotrifluoroethylene (CTFE) to it as it's formulated allows the material to polarize more easily, increasing its storage capacity, Ranjan says. The large CTFE molecules create spaces in the PVDF polymer chains, Buongiorno-Nardelli says, allowing the molecules to rotate more freely and become polarized when the capacitor is charged up. The researchers are running simulations to determine the optimal concentration of CTFE for peak performance and are studying whether other polymers exhibit the same characteristics. "There are many ways of storing electricity," Buongiorno-Nardelli says, "but our research will allow devices to store more than ever before."

# Ending Gridlock for Renewable Energy

**Looking out his office window on Centennial Campus, Progress Energy Distinguished Professor of Electrical Engineering Alex Huang stares past the brick buildings and open fields for a glimpse at the future.** He envisions an electric grid that will revolutionize the nation's power systems and speed renewable electric energy technologies into every home, car, and business. He hopes to make Centennial Campus his proving ground. "A green energy based society is our generation's moon shot," he says excitedly.

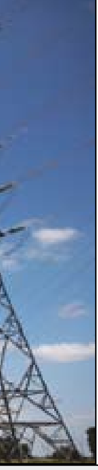
The National Science Foundation is so intrigued with Huang's idea that it has just awarded NC State an initial five-year, $18.5 million grant (augmented by $10 million in industry support) to launch the Engineering Research Center (ERC) for Future Renewable Electric Energy Delivery and Management (FREEDM) Systems. The ERC can be renewed for a second five-year period and already has commitments from 65 companies for membership fees. As the grant leverages related grant funding and industry contract research, the effort could translate into a ten-year, $100 million boon to NC State's energy research programs.


Dr. Alex Huang is leading the effort to create a new, smart electrical grid that relies on distributed sources of power, especially renewable energy.

The FREEDM Systems Center will develop a grid that relies more on smaller, regional electricity generators than on large, multi-state utilities. Huang compares the move to a distributed supply system to the changeover from mainframe computers to local-area networks. Creating a "plug-and-play system" for people to charge up their homes and cars on any source of power, from their own solar panels to a nearby wind farm, would open renewable energy to wider and more efficient use, he says. It would also relieve some of the 100-year-old "legacy grid" of some of its demand, especially at peak times. "We know how to produce renewable energy, but we don't have a way to consistently store and use the energy," Huang says. "We generate it, and we use it. We need more intelligent energy management that can store and balance supply and demand."

> "A green energy based society is our generation's moon shot."

Just as the Internet provided an information highway that linked computers nationwide, the FREEDM System will build the highway for renewable energy resources, allowing customers to invest in green technologies and sell excess energy back to the grid.




The Advanced Transportation Energy Center will work to improve the technology for plug-in hybrid vehicles, which are expected to be in commercial production in the next few years.

In its first five years, the FREEDM Systems Center will develop a one-megawatt demonstration grid to power the ERC's headquarters on Centennial Campus. The demonstration will rely on new fundamental research in post-silicon electronics, system theory, computer engineering, and storage technologies.

"This...will provide the knowledge and technology platforms the country needs to help reduce our dependency on fossil fuels and make our grid more secure."

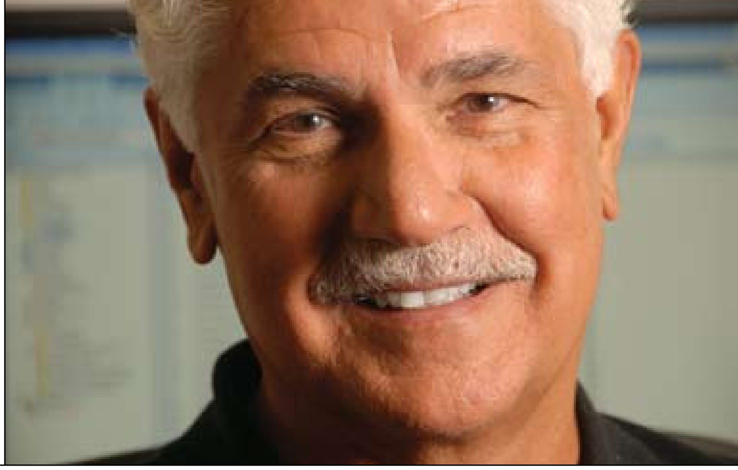
NC State researchers will work with scientists at Arizona State, Florida State, Florida A&M, Missouri University of Science & Technology, and German and Swiss partners to design and construct the new smart grid system. The international team is already working on the needed breakthroughs in energy storage, system control, and solid-state devices to make the enabling technologies for the FREEDM grid possible. "We applaud the collaborative spirit of Alex Huang's work," says Chancellor James L. Oblinger, "and believe the results coming from this NSF center will deliver broad changes in our nation's approach to energy. Solving the energy crisis is not just about generating renewable energy but also about developing the infrastructure needed for distribution. As more renewable energy becomes available, we and our research partners will help deliver it to millions of homes and businesses."

Plug-in hybrid vehicles, which can get up to 100 miles per gallon while slashing greenhouse gas emissions, will become a key component of the new grid. Gov. Mike Easley announced in February the creation of the Advanced Transportation Energy Center (ATEC) on Centennial Campus to improve the plug-in hybrid technology. State lawmakers, Progress Energy and Duke Energy are funding the center, and Advanced Energy Corporation, a consulting firm on Centennial Campus that has worked with plug-in vehicles for several years, is providing technical assistance such as road tests and market research. Huang, who will direct both ATEC and the ERC, says the FREEDM grid will allow plug-in hybrids to both charge up and supply energy. "Instead of having plug-in hybrids be just another load on the system, we can use them as a network of generators and pull from all that stored power as needed," Huang says.

In addition to its research efforts, the FREEDM Systems Center will train graduate and undergraduate students. The College of Engineering will create a new master's degree program and an undergraduate certificate program in renewable energy systems. The Science House in the College of Physical and Mathematical Sciences will coordinate a partnership with 14 public schools in North Carolina, Florida, and Arizona to train teachers to integrate engineering and renewable energy concepts into their science curricula and to offer renewable energy summer programs for students.

In announcing the center, Lynn Preston, leader of the NSF Engineering Research Centers Program, said "The unique vision of the FREEDM Systems Center to enable the smooth inclusion of renewable energy sources in the power grid in a 'plug-and-play' mode will provide the knowledge and technology platforms the country needs to help reduce our dependency on fossil fuels and make our grid more secure."

# Undergrads Try Hands at Energy Research



Undergraduate Research Director George Barthalmus says graduate schools and businesses want college students to conduct hands-on research with faculty mentors as early as possible.

**After spending part of his school year running computer simulations of a next-generation nuclear reactor, Justin Carey spent his summer working for GE-Hitachi Nuclear Energy, Inc., in Wilmington.** Back on campus, Alexandra Blalock performed energy-related classroom research that professors in the Colleges of Education and Engineering are using as the pilot project for a National Science Foundation-funded study.

Carey and Blalock aren't graduate research assistants conducting experiments while pursuing advanced degrees. They and 14 other NC State undergraduates won energy research fellowships funded last fall by the Office of Research and Graduate Studies and Progress Energy, Inc. The students proposed research projects and were selected in a competitive process, Director of Undergraduate Research George Barthalmus says. "These fellowships get them doing early hands-on work with mentors, which is what both our faculty and industry want," he says. Because of Progress Energy's commitment, students were asked to focus their research on topics like alternative fuels, energy conservation and efficiency, and education tools related to energy production and use.

Carey, a rising junior, simulated the power distribution in the core of a Generation IV nuclear reactor, a concept in the design phase and not expected to be operational for another 30 years. Increasing the accuracy of how the power distribution is measured will cut costs in building the reactor and allow it to be operated more efficiently, he says. "I was looking for an opportunity to get into research for some hands-on experience," he says. "The fellowship helped me land my internship with GE-Hitachi and will be important as I choose my future career path."

Work done by Alexandra Blalock, a rising senior, became a stepping stone for GRIDc, an NSF-funded project led by Dr. William DeLuca, a professor of math, science and technology education. The project's goal is to use renewable energy data collected by the NC Solar Center so students can analyze and synthesize it in various science and math contexts. Blalock tested the idea on a class of NC State students, allowing them to experiment with solar cells and construct their own wind turbines to determine if the projects increased their critical-thinking skills. "If I pursue a graduate degree," she says, "getting a taste of research now will help."

"The next generation of scientists is now sitting in undergraduate classrooms."

Barthalmus says the fellowship program will be expanded with more financial support in future years, especially for the dozens of undergraduate research experiences to be funded by the Future Renewable Electric Energy Delivery and Management Systems Center (see story on page 7). "The next generation of scientists is now sitting in undergraduate classrooms," he says. "We want these students to be prepared for graduate school and graduate research before they leave here."

Working as an intern at GE-Hitachi Nuclear Energy, NC State junior Justin Carey measures the activity of a motor that moves control rods into and out of a nuclear reactor core to maintain the stability of a reaction.
*Photo by Cathleen Wessely*

# Green Energy From Forests

Dr. Joe Roise says collecting small woody material from forests not only provides feedstock for ethanol production, it also eliminates dangerous fuel for wildfires.

**If a tree falls in the forest and no one is there, could it make biofuel?** NC State scientists are determined to answer this Zen-like question with a less philosophical "yes." The University is taking a vertically integrated approach to research on using cellulose in trees to make fuel, from harvesting the wood to processing ethanol to converting aging paper mills into biofuel refineries.

"Making ethanol out of biomass isn't just about making money—it's about national security."

Forestry professor Joe Roise didn't set out to be a biofuel feedstock collector. He was only trying to decrease the risk posed to suburbs by wildfires. Decades of wildfire suppression have left forests brimming with enough small trees to create a safety hazard if they go up in flames, he says. With funding from the U.S. Forest Service, Roise's research team worked with a mulching machine manufacturer to design a harvester that could drive through a forest, collect small woody material, grind it up, and dump it in a bin to be hauled away.

The researchers have been providing the chips to a wood-fired power plant in Craven County, but Roise says someone could easily process the material for ethanol if the economics are right. "Biomass is everywhere in the forests," he says. "The stuff we're after isn't on anyone's radar, and it can minimize the wildfire danger, improve forest ecosystems, and give us an energy source that doesn't cut into our food or timber resources."

Making ethanol production more cost-effective is Dr. Hasan Jameel's goal. One-third of the production cost is tied up in pretreatments to separate cellulose from lignin, the glue-like polymer that makes wood stiff. The pretreatments leave a chemical mess behind, so Jameel, a professor of wood and paper science in the College of Natural Resources, has devised an alternative, water-based separation process. He and Dr. Vincent Chiang, co-director of the Forest Biotechnology Group, have won grants from the U.S. Department of Agriculture and the Department of Energy to bioengineer and study the feasibility of growing genetically modified trees in North Carolina and using them to produce ethanol inexpensively. The poplars have a low lignin content, and the water in Jameel's high-temperature process dissolves the hemicellulose in the wood, poking holes in the polymer structure so enzymes can get around the lignin and break down the cellulose for processing.

To cut production costs even further, Jameel and Richard Phillips, a former International Paper executive now working in the Department of Wood and Paper Science, have calculated the economics of converting paper mills to ethanol production plants. Building a plant from scratch to produce 100 million gallons a year could cost $500 million, while converting a paper mill could cut that in half, Jameel says. NC State is part of a team that is trying to produce six million gallons of biofuel a year at a Wisconsin paper mill under a recent Department of Energy award. "These are not mom-and-pop operations," Jameel says. "Making ethanol out of biomass isn't just about making money—it's also about national security."

Dr. Hasan Jameel's water-based technology transforms wood into a lump of cellulose that enzymes can begin turning into ethanol.

Drs. Anne-Marie Stomp and Jay Cheng say duckweed, a rapidly growing aquatic plant, can be engineered to produce starches that can be used to make ethanol. Duckweed (below) can also filter excessive nutrients out of hog-waste lagoons as it grows.

# Researchers Find Fuel in Odd Places

**While much of the national attention on biofuels has been directed at corn-based ethanol, NC State researchers are looking at creating fuel from everything from animal fat to pond scum.** Even microbes that eat carbon dioxide while producing ethanol are being investigated as a possible future source of fuel.

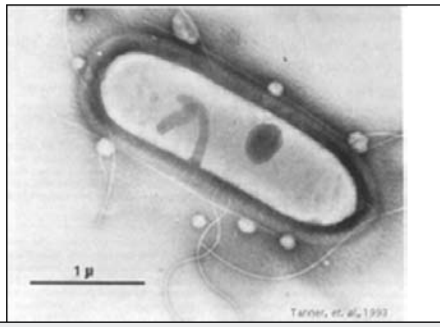
The focus on corn for fuel production has shifted thousands of acres from agricultural production into the ethanol pipeline, raising food prices in the process as U.S. demand for corn-based ethanol begins to outstrip the amount of available crop. Producing enough ethanol to replace gasoline in the U.S. for a single day would require more than 100 million acres of corn—more than farmers nationwide have planted this year. "You plant corn and get one crop a year," says Dr. Jay Cheng, an associate professor in the Department of Biological and Agricultural Engineering (BAE). "We need to develop sources for fuel that are more renewable and won't divert our nation's food resources."

Cheng and Dr. Anne-Marie Stomp, an associate professor of forestry, believe duckweed fits the bill on both counts. The tiny aquatic plant, which creates a scum on the surface of ponds, doubles its mass every few days and can be manipulated as it grows so that up to three-quarters of that mass is starchy content that can be broken down and fermented into ethanol. Because the duckweed can be harvested almost daily, it can produce four times the amount of ethanol per acre as corn, says Stomp, who previously modified the plant to produce proteins for pharmaceuticals.

The two NC State professors recently won a grant from the North Carolina Biofuels Center to grow duckweed on hog-waste lagoons in eastern North Carolina for ethanol production. The plant consumes the excess nutrients from waste lagoons, cleaning the water as it grows. Farmers would need to be trained to grow and harvest duckweed, Stomp says, but the crop could produce jobs in rural North Carolina—as well as fuel and cleaner water. "George Washington Carver made the peanut into a multiple-use crop," she says, "NC State will do it with duckweed."

NC State researchers are looking at creating fuel from everything from animal fat to microbes to pond scum.

The University also could do it with microbes known as clostridia and methanogens, which Drs. Amy Grunden and Mari Chinn are using as a tag team to convert carbon dioxide and carbon monoxide into ethanol and methane. *Clostridium ljungdahlii,* for example, lives in the soil and naturally consumes carbon dioxide and carbon monoxide for energy, producing acetate and a small amount of ethanol in the process. Grunden, an associate professor of microbiology, says fooling the organism is the trick to transforming it into an effective fuel-producer. Treating the cells with chemicals like hydrogen peroxide, oxygen and hydrogen convinces them to alter their metabolism, she says, so they give off more ethanol and less acetate. *Methanosarcina barkeri,* By using a bit of trickery, Drs. Mari Chinn (left, at right) and Amy Grunden can get two types of microbes, clostridia (right) and methanogens (below far right) to consume carbon dioxide and acetate, respectively, and produce ethanol and methane.




an organism more known for making swamp gas, can then be used to consume the acetate and create methane.

Chinn, a BAE assistant professor, is trying to improve the efficiency of the fermentation processes in which the two microbes become a cellular-level refinery. With the help of Dr. Michael Flickinger, a professor in the Department of Chemical and Biomolecular Engineering and the Department of Microbiology, she and Grunden are embedding the organisms in a latex film to protect them from noxious compounds in the gas stream that can inhibit the ethanol production—or even kill the organisms. Chinn and Grunden recently won a grant from the North Carolina Biotechnology Center to test their process. “We’ve shown that different parts of this process work,” Grunden says. “Now, we have to put it together and prove it can be an efficient production model.”

“George Washington Carver made the peanut into a multiple-use crop. NC State will do it with duckweed.”

Chemical and biomolecular engineering professor Henry Lamb, mechanical and aerospace engineering professor William Roberts, and BAE professor Larry Stikeleather are using the proven model of an oil refinery to convert animal fat and vegetable oils into gasoline, jet fuel, and diesel. Their three-step process, dubbed Centia for “green power” in Latin, uses high-temperature hydrolysis to break triglycerides in the fats and oils into free fatty acids. Proprietary catalysts are then introduced to produce hydrocarbons and refine them into the desired fuel type. “We knew there was chemistry out there to get us started,” Lamb says, noting that mechanical and aerospace engineering graduate student Tim Turner found published research in which scientists were able to remove $CO_2$ from fatty acids to make hydrocarbons. “The hydrolysis step allows us to start with any type of fat,” he says, “and we’ve synthesized the process from there.”

“We need to develop sources for fuel that are more renewable and won’t divert our nation’s food resources.”

The team recently won a North Carolina Biofuels Center grant to demonstrate that the process can produce different fuels and to test the fuels in standard engines. Lamb is convinced Centia fuels, like the duckweed research, could be a boon to North Carolina’s agricultural economy. He grew up on a hog farm in southeastern North Carolina and says farmers have expressed interest in making fuel from hog rendering—as close to making a silk purse from a sow’s ear as you can get. “Ethanol has limitations,” he says. The fuel delivers less energy per gallon than gasoline and is difficult to transport because it absorbs moisture from the atmosphere. “Instead, we’re trying to develop conventional transportation fuels from non-petroleum sources.”

Drs. Henry Lamb (left) and Bill Roberts are part of an NC State team to develop a three-step process to convert animal fat and vegetable oils into fuel.

# Fuel, Driving Habits Affect MPG

Dr. Chris Frey (top) and graduate research assistant Hyung-Wook Choi (bottom, at right) monitor the emissions produced by different vehicles and different fuels.

**Want to put a tiger in your tank? Don't start with a corn cob, say NC State researchers, who have compared the fuel economy and emissions of various biofuels with regular gasoline and diesel.**

Dr. Chris Frey, a professor of civil, construction and environmental engineering, test drives various cars, minivans, and SUVs to obtain second-by-second data on engine performance and tailpipe emissions for traditional versus alternative fuels. Likewise, he tests biodiesel in tractor-trailers, dump trucks, and construction vehicles. "Ethanol is an alternative to oil but is not yet as good from an efficiency and emissions standpoint," Frey says. "Biodiesel provides a more favorable comparison."

The energy density of ethanol is lower than gasoline, Frey says, meaning vehicles running on ethanol get fewer miles per gallon. Ethanol does cut carbon monoxide emissions in the "field-to-tank" tests, he says. But biodiesel does even better, cutting greenhouse gas emissions and particulate pollution without sacrificing much energy when compared with petroleum-based diesel. Frey also is working with NC State's Institute for Transportation Research and Education (ITRE) to study the fuel economy and emissions of plug-in hybrid and fuel cell vehicles. Hybrids will reduce energy consumption by up to 20 percent, he says, but it will take years for people to swap out a significant percentage of older vehicles for hybrids.

"How cars are driven is a major contributing factor to energy use and emissions."

Miles per gallon is only part of the equation for more energy-efficient vehicles, according to ITRE Director Nagui Rouphail. "How cars are driven is a major contributing factor to energy use and emissions," he says. Data that Frey has collected show aggressive driving—jack-rabbit starts and stops, and speeding—uses far more fuel than trying to maintain a constant speed as much as possible. Proper timing of traffic lights to reduce idling was also found to cut fuel consumption and emissions. Research at ITRE using traffic predictions for the Raleigh-Durham region shows that an expansion of the current sprawling growth pattern over the next 20 years will produce increased fuel use and emissions even when newer, more efficient cars take to the highways.

Ethanol cuts carbon monoxide emissions in the "field-to-tank" tests, but biodiesel does even better.

Rouphail says ITRE is also working with regional planning researchers at UNC-Chapel Hill on a computer model to study the impact of a "smart growth" land-use plan for Charlotte that would reduce vehicle miles traveled and slash fuel consumption. "A combination of factors needs to be looked at to decrease energy use," he says. "It's really a complex picture for which there is no single silver bullet."

ITRE Director Nagui Rouphail says properly timed traffic lights can reduce fuel consumption and vehicle emissions.

Photonics Leaders director Pam Gilchrist checks the wiring of a student's circuit board during a summer session of the hands-on program for 11th- and 12th-graders.

**With the nation's energy future at the top of today's news, hands-on learning related to energy is opening the door to future energy careers for students touched by the College of Education (CED) and The Science House at NC State.** Research on the best teaching methods for interactive experiments is the key to unlocking that door.

"This is a field where even one bright new scientist can have a tremendous impact on our energy future."

Middle school students and teachers in eight districts, for example, test pistons and headlights, make radiators out of soda cans, and design solar-powered model cars. The work engages the students while teaching problem-solving and analytical skills, says Dr. Lisa Grable, the director of the CED's Office of School Services. Grable and her colleagues studied economic forecasting data and information on biofuels projects to plan the curriculum and used the results of a statewide technology implementation project to choose classroom equipment. "These students are more motivated," she says. "They're still doing math and science work, but they're using their own data instead of working out of a book."

Grants from the Friday Institute for Educational Innovation and the UNC General Administration provide each student with a graphing calculator with sensors for collecting data and each teacher with a laptop computer loaded with analytical software. Teacher training for the project is conducted through a combination of site visits and video-conferencing, allowing CED researchers to refine distance learning techniques. "We're promoting student inquiry," Grable says, convinced that it will impact student achievement.

To prepare high school students for 21st century energy careers, The Science House in the College of Physical and Mathematical Sciences launched the Burroughs Wellcome Fund Photonics Xplorers program five years ago. About two dozen ninth- and 10th-graders spend one week each summer on Centennial Campus and visit monthly during the school year to conduct experiments developed through staff research to learn about the properties of light, optics, and electromagnetism. "Students can relate to photonics since light is used in DVDs, lasers, cell phones, and telecommunications," program director Pamela Gilchrist says. "These applications show how science disciplines merge to create new possibilities."

Three years ago, the National Science Foundation funded the Photonics Leaders program, allowing The Science House to offer a more advanced program for 11th- and 12th-graders. The program provides more hands-on physics and research and mentoring opportunities with NC State faculty and scientists with companies like Cisco Systems and Verizon Business. Gilchrist says the time spent in the lab gives students a chance to explore science as a career option before heading to college. "This is a field," she says, "where even one bright new scientist can have a tremendous impact on our energy future."

**On the cover:** The nation's electric grid is the focus of NC State's transformative Engineering Research Center for Future Renewable Electric Energy Delivery and Management Systems. The National Science Foundation announced the Center's award in September 2008, providing $18.5 million in funding for its first five years, to be supplemented by $10 million in industry membership fees and sponsored research. (see story on p.7)

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