Science & Technology HIGHLIGHTS

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Will Smart Grids Generate Changes in Electricity Use?

The aging electricity transmission and distribution system in the United States is prone to brownouts and blackouts when demand for electricity reaches the daily peak, especially during a long, hot summer, when the need for air conditioning (AC) is enormous. Demand for electricity is expected to grow by 30% by 2035, so one solution to America's problem is to apply available and new technologies to create a smart grid, potentially reducing electricity use by 4%. "The smart grid will use advanced technologies to optimize the delivery of electricity from power plants to customers safely, efficiently, reliably, and securely," said Russell Lee, a social scientist on the energy analysis team of the Renewable Energy Group of ORNL's Environmental Sciences Division.

For decades utilities have been determining the amount of electricity each building consumes by sending out meter readers to record the total kilowatt hours used monthly, as displayed on each outdoor meter. Replacing old meters with "smart meters" that enable two-way digital communication between the electric utility and customer will help bring the U.S. electric grid into the twenty-first century.

Smart meters—manufactured by companies such as GE, Itron, and Landis+Gyr—cost between $100 and $250, including installation. A smart meter, which has an easy-to-read digital display, measures and records power consumption several times every hour and relays the data daily over a network to the utility for monitoring and billing purposes. Information technology enables each customer and electric utility to monitor and control the amount, times, and cost of the building's electricity consumption each day.

The U.S. government has instituted a Smart Grid Initiative, which has received $4 billion in funds from the American Recovery and Reinvestment Act of 2009. Some $3.4 billion of this amount is for the Smart Grid Investment Grant Program, designed to accelerate utility deployment of smart grid systems.

The program supports 100 smart grid projects throughout the nation, ranging in size from Consolidated Edison's $190 million project in the New York City area, to the more modest, such as the $8 million project undertaken by the Knoxville Utilities Board in Tennessee. The projects include 30 that will test new technologies and 10 that will conduct experiments to study changes in the electricity-consumption behavior of customers with smart meters compared with control groups without.

Some utility projects will test advanced metering infrastructure with dynamic pricing if the pricing rates are approved by state public utility commissions. Instead of charging the usual flat rate for electricity use in kilowatt hours, the utility will charge more for electricity consumed during hours of peak demand (say, from 12 noon to 8 p.m. or from 2 to 6 p.m.) and much less during off-peak hours, when demand tapers off.

"The idea is to provide disincentives for consumers to use power during those hot afternoons when demand for AC is high, to reduce strain on the transmission and distribution system," Lee explained. "To meet peak demand, utilities must turn on more expensive generators, such as natural gas turbines and generators fired with oil, increasing carbon dioxide emissions."

It is hoped that customers will buy into the smart meter–dynamic pricing concept. If they respond intelligently to the information at their fingertips about the amount and cost of the electricity they use hourly, they should enjoy a lower annual electricity cost than they have now with the flat rate. They will likely be motivated to operate their dishwasher, washing machine, and electric dryer during off-peak hours and raise the AC thermostat from say, 72˚F to 78˚F, during peak hours in the summer, in exchange for a much lower off-peak electricity rate.

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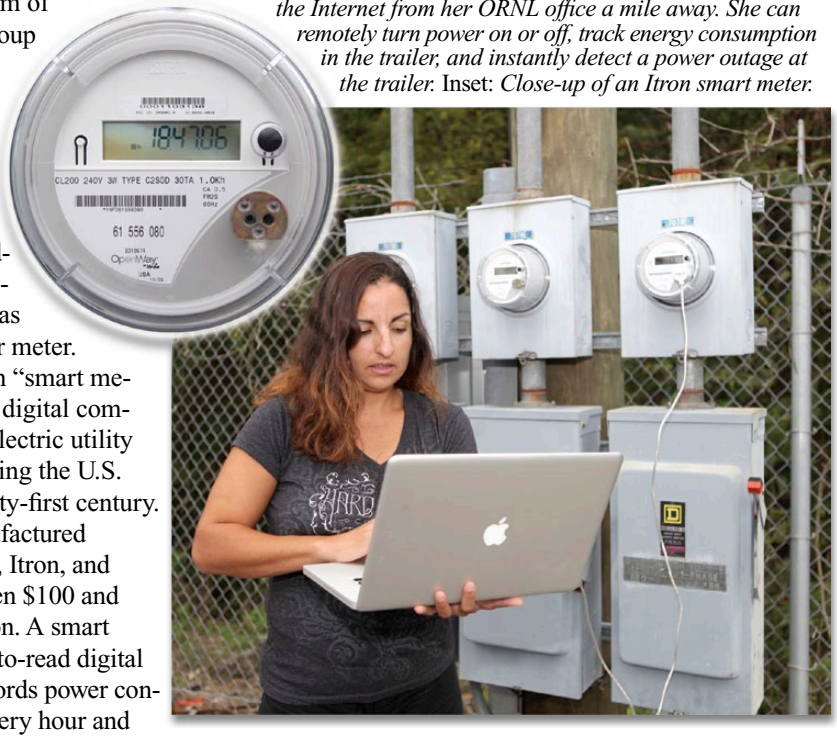

By tapping keys on her laptop, Isabelle Snyder communicates with an Itron smart electric meter, one of three smart meters installed on a pole near a trailer at ORNL. Snyder can also control the smart meters over the Internet from her ORNL office a mile away. She can remotely turn power on or off, track energy consumption in the trailer, and instantly detect a power outage at the trailer. Inset: *Close-up of an Itron smart meter.*

On August 31, 2010, Secretary of Energy Steven Chu (shown here at ORNL) announced at Battelle headquarters in Columbus, Ohio, that two million smart grid meters have been installed nation-wide. "Smart Grid technologies will give consumers choice and promote energy savings, increase energy efficiency, and foster the growth of renewable energy resources," he said.

Smart Grids continued from p. 1

Also, under demand response contracts, customers will have remotely controlled switches on appliances and equipment and, in return for financial incentives, will permit utilities to send signals to periodically slash electricity use by AC, appliances, and other equipment under certain conditions.

Smart grid devices for power transmission and distribution systems will be installed in some of the projects. For example, sensors and phasor measurement units will monitor in real time (20 data points per second) the quality of the power and detect abnormal deviations in voltage and current in transmission lines. Substations and the central utility office will digitally communicate with each other and respond rapidly to undesirable changes in power characteristics of the regional grid. Automated switches and visualization systems, such as those developed at ORNL, will enable just-in-time diversion of electricity from power lines to prevent them from overheating, stretching, and sagging into trees, thus averting short circuits and cascading power outages.

Yilu Liu, a University of Tennessee–ORNL Governor's Chair Professor, is using the GPS time-synchronized wide area measurement system to monitor the North America power grids very inexpensively. Such information can be used to make the grids smarter. "The tools we are developing at ORNL," she said, "are like CT scanners that will allow operators to view the grid inside out and as one whole system, to operate it more intelligently as renewable generation and smart-grid loads grow, and to 'see' the edge of instability to enable reliable operation of the power grids near, but not beyond, the edge."

Will the benefits of a smart grid to customers, utilities, and society at large outweigh the costs and negative impacts? The U.S. government, the utilities, state regulators, the news media, and many customers will want to know the results of the 100 projects supported by stimulus funding.

Lee communicates weekly with researchers from other DOE national labs about the best ways to gather, categorize, and analyze high-quality data expected from most of the 100 projects in 2011. Already, researchers from Lawrence Berkeley, National Energy Technology, National Renewable Energy, Oak Ridge, and Pacific Northwest laboratories are developing a secure place for the data on the www.smartgrid.gov website, which will eventually provide the results of the data analyses to other researchers and the public. Starting in 2011, the projects will report "build metrics" quarterly and "impact metrics" twice a year. Lee and his colleagues will soon be analyzing smart grid project data and providing results.

Build metrics include a count and description of smart meters, phasor measurement units, sensors, capacitors, switches, hardware, and software packages in each smart grid project (projects will have some but not all of these devices and systems). Impact metrics will quantify the economic, reliability, environmental, and security benefits of the smart grid projects.

Economic and financial benefits include reduced needs for meter readers, line crews, and the vehicles they use; reduced operations and maintenance costs and deferred capital costs; and less reliance on higher-cost (and also more carbon-emitting) power generators during peak hours. The likely reliability benefits will be reductions in damaging power outages and in brief voltage deviations that can harm computers and electronics. Environmental benefits will be reduced emissions of pollutants and greenhouse gases. Security benefits will include less dependence on imported oil as a result of the reduced need for truck trips for power-line maintenance and meter reading, decreased use of oil-fired power plants, and greater use of electric vehicles (whose charging schedules are optimized by a smart grid).

Cybersecurity of the smart grid is another important issue being addressed by DOE and ORNL as part of a multiagency task force led by the National Institute of Standards and Technology. Unless the two-way flow of data among utilities and customers is secure, the risk remains that intrusions by hackers and terrorist groups might cause blackouts or even the collapse of large parts of the U.S. power system. The smart grid of the future will be designed to thwart such threats to the reliable delivery of electricity and to deliver it at lower cost and with less environmental impact than our current, outdated grid.

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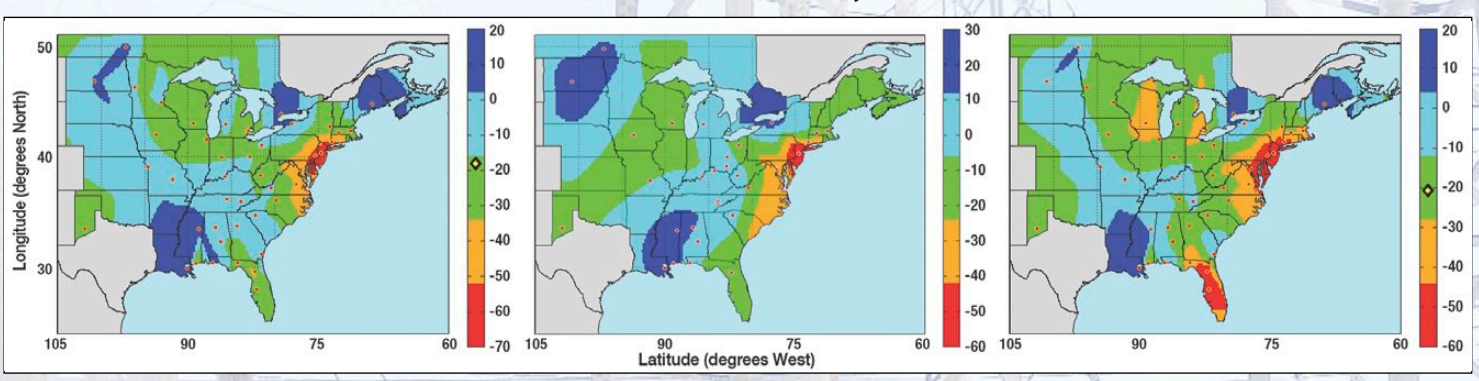
Sponsor: DOE Office of Electricity Delivery and Energy Reliability



The visualizations of the power grid in the eastern half of the United States indicate changes over time from a normal to a stressed condition for many regions, as detected by GPS-enabled phasor sensors.

ORNL Pioneers Titanium Powder-to-Product

Titanium is often considered a valuable metal. In fact, this lightweight element that is more corrosion resistant and stronger than some steels is the fourth most abundant metal and the ninth most abundant element in the earth.

Craig Blue and Bill Peter show brake rotors made from consolidated titanium powder.

Titanium, which is highly reactive with both oxygen and nitrogen in air, is present in its ore as titanium dioxide, commonly used as a white pigment for paints. What makes titanium metal for aircraft engines and structural parts so expensive are the difficulty of separating the metal from its oxide and the need to sacrifice costly magnesium to win titanium from its ore.

Bill Peter, leader of the Materials Processing Group in ORNL's Materials Science and Technology Division, explained that the commonly used Kroll process is the key to titanium's relatively high market value. After titanium forms a Kroll "sponge," the porous metal is melted, or combined with a master alloy, to form an ingot. Milling operations on a 10,000 lb. ingot include hot rolling it into sheets and plates and extruding it to form tubes and bars.

Almost 80% of all milled titanium products are consumed by the aircraft industry, which has a "buy-to-fly" ratio of 8 to 1. In other words, for every 8 pounds purchased, only 1 pound of titanium is part of a finished shape while 7 pounds are machined away and recycled as scrap.

ORNL's initial work with titanium was funded by the Office of the Secretary of Defense. Since 2003 ORNL researchers have been collaborating with industry on finding less expensive and less energy-intensive ways to process titanium and form it into structural parts.

ORNL has partnerships with various companies to identify cost-effective methods of shaping low-cost compact powders into products. The goals are to significantly reduce the number of machining steps, amount of scrap, energy consumption, and costs.

ORNL researchers and partners have demonstrated the potential of the powder consolidation route for manufacturing low-cost titanium products. They have developed technology that enables the production of alloy sheets and near-net-shape components from low-cost powders supplied by International Titanium Powder (ITP). ORNL was a partner in winning a 2007 R&D 100 Award for the technology.

"Our goal is to save energy by consolidating powders at 900 to 1100˚C, which is lower than titanium's melting point," Peter said. "Consolidating powders into solid forms should also reduce the processing cost and the amount of scrap.

"We are using hot roll compaction to press titanium alloy powders into 20-mil-thick heat exchanger plates for desalination units that use power plants' leftover heat to turn seawater into salt-free drinking water. We have a new approach that may reduce the cost of converting sheet to heat exchanger plate by over 50%.

"We can press some titanium alloy powders with new particle morphologies into a shape before sintering them. Because the irregular shapes of the particles allow the powder 'arms' to interlock with each other, we can press these powders to a higher density of 25 to 30% without using binders."

The project received American Recovery and Reinvestment Act funding of $2.5 million, enabling ORNL to set up contracts with powder vendors and purchase the latest roll compaction and inert hot rolling equipment, which rolls powders without exposure to air.

"By using the new inert hot rolling mill on titanium powders, we will eliminate some expensive rolling steps used in conventional scenarios, making the process more cost effective," Peter said. "In one project we showed Lockheed Martin how to reduce the buy-to-fly ratio for one titanium component from 33:1 to 4:1." For industry and the military, this is valuable knowledge, indeed!

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Sponsors: Office of Secretary of Defense, Defense Advanced Research Project Agency (DARPA), DOE EERE Vehicle Technologies Program and Industrial Technologies Program, Work-for-Others projects with industrial firms (Ametek, AquaChem, ITP, Lockheed Martin, Boeing)

Titanium aircraft parts can be produced by roll compaction and inert hot rolling.

"New Product" Award for ORNL's Gas Engine Heat Pump

A gas engine–driven heat pump (GHP) devised by an ORNL team received the New Product Award in 2010 from the National Society of Professional Engineers.

As the first viable system of its kind designed for commercial applications, the GHP is a significant advance. IntelliChoice Energy, which manufactured the first units, began selling them in the second quarter of 2010 under the NextAire brand name.

The engine in the rooftop units for commercial buildings is about the size of a small automobile engine and has the power delivery of a riding lawn mower. Fueled by natural gas, the GHP engine delivers 9 horsepower for driving the compressor for the refrigeration system, providing heat or cooling. The electricity the unit draws from a central power station is used only for the fans, controls, blower, and pump.

The success of the ORNL project has spurred the development of additional innovative products, such as a residential version funded by the DOE Building Technologies Program. The U.S. Department of Defense has funded a field test of the GHP unit to investigate potential applications for military bases to reduce peak electrical demand.

The ORNL team, led by Ed Vineyard, developed the GHP using funding from DOE's National Energy Technology Laboratory. The project was a cooperative effort with Team Consulting, Blue Mountain Energy, and Southwest Gas. A new company, IntelliChoice Energy, was formed to produce the units.

The GHP unit uses 85% less electrical energy at high ambient temperatures compared with an equivalent size electrical heat pump. A study done for the Arizona-Nevada region concluded that the potential benefit of the technology, if used widely in the region, would be a reduction in peak electricity demand. The reduced demand would result in a savings of $4.4 billion by delaying or eliminating the need for 4,143 megawatts (MW) of future central station construction, the equivalent of two power plants. On a national basis, the savings would be even higher.

Because the Southwest is the fastest growing region in the country, the peak demand savings have an even greater impact on the region. Water limitations as a result of the arid climate, need for irrigation to grow crops, and increased population demands impose constraints on proposals to build new power plants that require water cooling. In addition to the peak demand savings, the high heating and cooling coefficient of performance (COP) for GHP units—the high amount of heat provided or removed for each unit of energy consumed—reduces greenhouse gas emissions and water usage at the central power plant because less electrical energy generation is needed.

Winners of the New Product Award in 2010 from the National Society of Professional Engineers for ORNL's gas engine–driven heat pump are, from left in front, Ed Vineyard (principal investigator) and Abdi Zaltash, and from left in back row, Randall Wetherington, Pat Geoghegan, and Randy Linkous.

The NextAire gas engine heat pump is based on the award-winning ORNL invention.

"By reducing the first costs, maintenance costs, size, and weight and by achieving the COP goals for heating and cooling, we have made the GHP unit a viable product for commercial use," said Vineyard.

"Previous attempts to achieve a marketable GHP failed as a result of a low cooling COP, high first costs, inappropriate unit size and weight, and the high costs of short maintenance intervals."

Design challenges for the GHP unit included the ability to operate at high ambient temperatures (51.7˚C, or 125˚F) and a marketable unit size and weight. The engineering team achieved the COP goals of the project—a design cooling COP of 1.2 at 35˚C (95˚F) and a design heating COP of 1.5 at 8.3˚C (47˚F).

What innovations make the GHP so readily marketable? "The GHP uses approximately 15% of the electrical energy from a central power station required by a conventional rooftop heat pump," said Vineyard. "The GHP uses mostly on-site engine energy and waste heat from the engine that supplements space heating, reducing CO_2 emissions and the need for electricity during the heating season."

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Sponsor: DOE EERE Building Technologies Program

Reliable Wireless Sensors for Steel Mills

Recognized worldwide as the leading laboratory on wireless technology for heavy industry, ORNL has been given the opportunity to prove that wireless technology can help the steel industry save energy.

DOE's Industrial Technologies Program (ITP) has commissioned ORNL to install and operate commercial wireless sensors and controls in two steel mills to assess the energy-saving benefits of the deployed technologies. The operational tests must commence before the end of FY 2010 with a total system cost of $2 million.

The steel mills are U.S. Steel's Edgar Thompson Steel Works in Braddock, Pennsylvania, and Consolidated Metals Corporation (CMC) in Cayce, South Carolina. Glenn Allgood, a researcher in ORNL's Computational Science and Engineering Division, is the principal investigator on the project. He said that Andrews Industrial Controls, Inc., has been selected as the vendor for U.S. Steel.

In August 2010 requests for proposals were sent to vendors seeking responses for the installation of appropriately defined commercial wireless technology in the steel mills. Sensor measurements will include electric motor temperature and vibration, which will be sent by secure radio signals to plant operations personnel and archived for energy analysis.

Sensor detection and communication of abnormal temperatures and vibrations will enable steel mill operators to identify and replace electric motors starting to overheat, waste energy, and vibrate excessively before motor failures force a downtime, which costs hundreds of thousands of dollars per day. The energy penalty could be even worse in the long run. Going wireless will also save the steel industry the cost of wire ($200/ft) used for wired sensors that monitor critical motors—a price that is escalating as copper and labor costs rise.

Allgood will supervise the wireless technology installations and demonstrations in two different steelmaking environments. The U.S. Steel mill makes high-quality steel from iron ore, and the CMC mini-mill transforms steel scrap into rebar for reinforcing concrete used in buildings.

"Our goal is to roll out wireless technology into two steel mills and demonstrate that wireless sensors and controls save energy," said Wayne Manges, a program manager in Measurement Science and Systems Engineering Division, co-chair of the ISA100 wireless standard committee, and internationally recognized expert on industrial wireless technology. He has been an advocate of industrial wireless technology since 1996, when he published papers and co-chaired a workshop at ORNL on the potential of this technology.

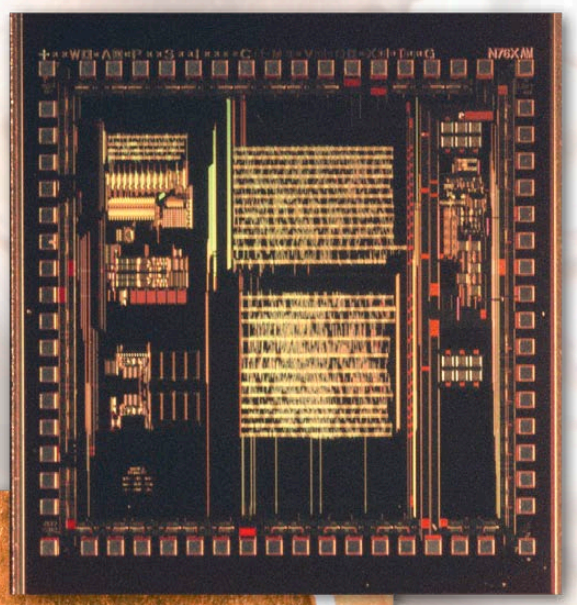
In 1998 the National Academy of Sciences published a report based partly on the workshop talks. The Academy report, which concludes that wireless technology could help industry save energy, served as a guide for ITP's future energy efficiency research. President Clinton asked the Presidential Advisory Committee in 1999 how much industrial energy would be saved using wireless technology. The answer given was 10%.

The nuclear power industry has been an early adopter of wireless technology, largely because the complicated installation of wire for monitors in a nuclear power plant costs $2000/ft. Manges cites the following example as a success story.

"Comanche Peak Nuclear Power Plant in Texas has the largest installation of wireless sensors in the world," he said. "Azima of Boston installed its own sensors, collects data from the sensors, and sells the data back to Comanche Peak at $1,000 per data point per year."

Nevertheless, the wireless sensor system at Comanche Peak paid for itself in one year. The reason: the sensor-based condition monitoring system revealed in real time when a motor or other equipment is running too hot or vibrating too much, indicating that failure is imminent. Through timely replacement of 14 pieces of equipment before they failed, Comanche Peak last year avoided 14 days of downtime, saving $14 million, which covered the costs of the wireless technology and data service.

Wireless technology is becoming more acceptable, Manges said. The wireless community, including ORNL, has developed the technology, formed an advocacy group called the Wireless Industrial Networking Alliance (WINA) to promote industrial adoption of wireless technology, and issued a wireless standard.



This 1/10 in. square chip was developed by ORNL's Steve Smith in 1998 as a sophisticated wireless temperature sensor that transmits difficult-to-intercept, frequency hopping radio signals. Navy officials were surprised when ORNL researchers demonstrated that the sensor could measure temperatures throughout a steel ship because radio waves sneak through air in catwalks and rubber in door gaskets.

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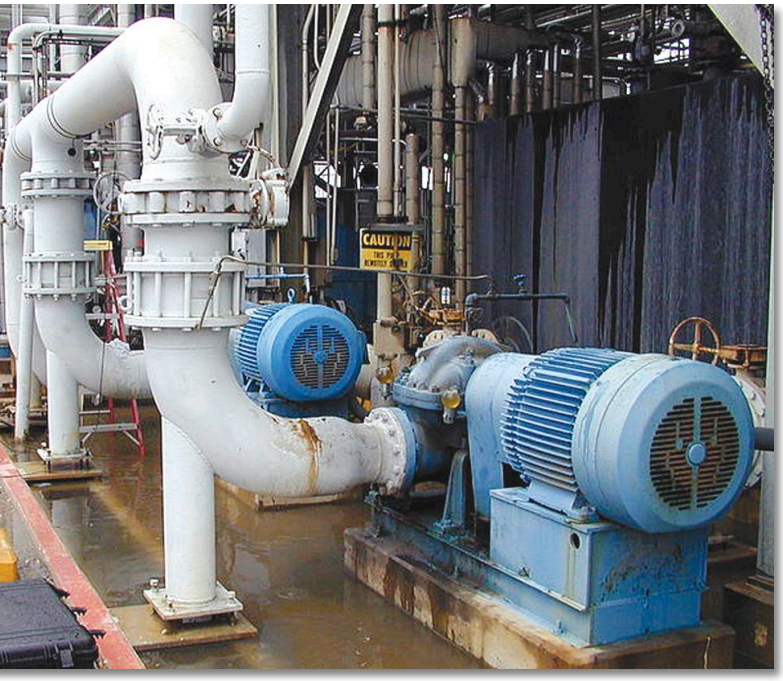
Sponsor: DOE EERE Industrial Technologies Program

Inducing Industry to Cut Energy Costs



DOE wants the implementation of energy-saving measures in industry, such as the replacement of inefficient pumps, to double by 2020.

In 2004 the U.S. industrial sector used more energy than any other developed nation. It consumed 33% of the energy and 37% of the natural gas used in the United States.

In 2005, Hurricanes Katrina and Rita devastated parts of Louisiana, Mississippi, and Texas. As a result, natural gas production declined and gas prices rose. Energy Secretary Samuel Bodman initiated a timely action: interest U.S. industry in learning ways to curb its natural gas consumption to cut its energy costs. Bodman announced that DOE's Industrial Technologies Program (ITP) would conduct three-day assessments of energy use and savings opportunities in 200 of the largest industrial plants.

A group led by ORNL's Tony Wright won the job of providing key technical support to DOE's Save Energy Now program for industry. The group played a major role in the program, which started in 2006 and is continuing.

"For the Save Energy Now program we have been working with large companies that are major energy users to assess their energy use and identify ways to reduce it," Wright said. "We lead efforts to conduct assessments, identify opportunities to improve energy efficiency in different systems of industrial plants, develop software tools to make calculations to track energy use, and train industry employees to use the software tools. We trained or identified close to 40 qualified specialists."

In 2006 the DOE focus was on process heating and steam systems in large industrial firms because they use so much natural gas. In 2007, the program was expanded to include other key energy-using systems, such as pumps, compressed air systems, and fans. During 2006–2009, 793 assessments were completed.

"Almost all DOE staff managing the efforts were immediately surprised by the magnitude of the potential energy-savings opportunities identified," Wright said. "We focused on large plants that consumed at least a trillion BTU of energy a year, which often translates into an annual energy consumption cost of $10 million. We identified potential energy savings for each plant that totaled $2 million to $2.5 million a year. For all 200 plants we identified approximately $500 million per year of energy-savings opportunities."

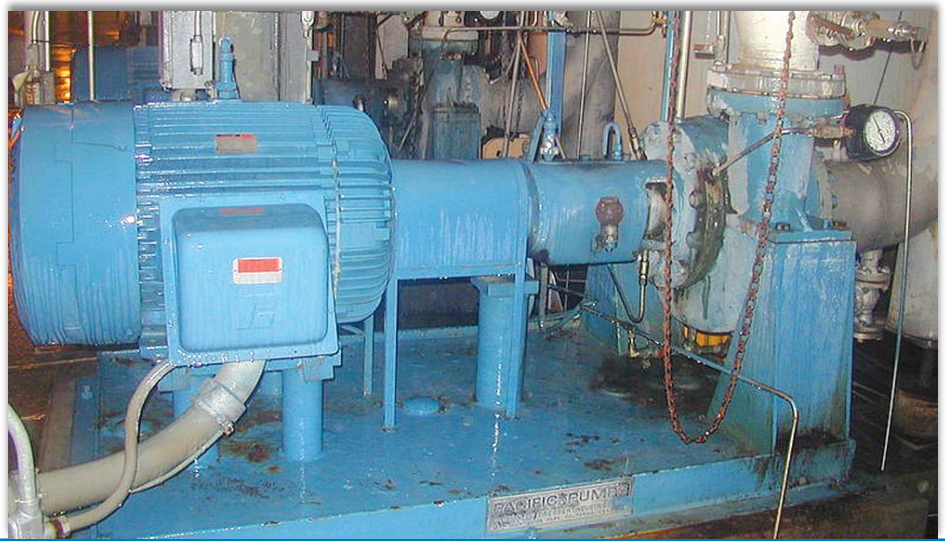
The challenge is that not all the plants took the advice offered by the assessments. Some industrial plants are reluctant to implement energy-saving measures because of their concern that the new measures will interfere with the manufacturing process or cost more than the savings over a few years from lower energy bills. Today the ITP focus is on increasing both the rate of implementation and penetration of energy efficiency technologies into the industrial sector.

"We have created the position of technical account manager, a person certified to help plants identify energy-savings opportunities and the kind of resources appropriate for them," Wright said. "We assist them in reducing financial risk."

ORNL and a Virginia corporation each won ITP funding to lead teams to help industry implement energy efficiency measures, such as replacing an oversized pump with the right size pump for the production process. DOE wants implementation of energy-saving measures to double by 2020.

Another ITP initiative resulted from a new federal law: Any company that voluntarily commits to reducing its energy intensity by 25% in 10 years will receive resources from DOE to help the firm achieve the goal.

"We are creating processes for working with each company designated as a *Save Energy Now* LEADER," Wright said. "The goal is to enhance the effectiveness of our assessments of energy use and savings opportunities."



Replacing an oversized pump with the right size pump can reduce energy consumption in an industrial plant.

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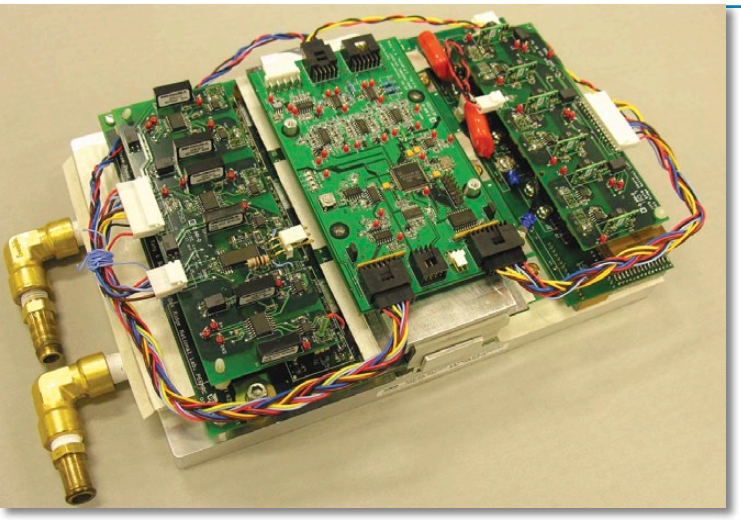
Sponsor: DOE EERE Industrial Technologies Program



A 6.5 kilowatt triple voltage dc to dc converter invented at ORNL.

More Power to Passengers

ORNL researchers led by Gui-Jia Su have invented a highly efficient, compact, direct current (dc) to dc converter. The triple voltage dc to dc converter module can step up or down dc voltage levels in battery-powered electric vehicles, meeting the multiple needs of drivers and passengers. The innovation will improve performance and reduce the size, weight, and cost of each vehicle, helping meet DOE goals.

In a hybrid, plug-in hybrid, and all-electric car, multiple voltage levels are required as well as the generation of alternating current from the battery voltage (typically around 300 volts) to drive the electric motor. Increasing vehicle electrification results in a growing number of power demands on the system, including power steering, power brakes, heat or air conditioning, power seats and windows, a radio, a CD player, GPS navigation, and a TV-DVD system for entertaining backseat passengers.

Electrical systems can provide the power required for the vehicle's increasing electrical loads more efficiently than can conventional engine-driven mechanical systems, but additional voltage buses are required for electrical systems to function optimally. Traditionally, a 14 volt bus has been used for low-power accessories such as brake lights, headlights, horns, and windshield wipers. As vehicle electrification grows, higher voltage levels are needed to supply increased power requirements efficiently and economically. Some manufacturers have proposed adding a 42 volt bus because multiple electrical power supplies that provide multiple voltages are needed for passenger accessories and safety features.

In today's technology, multiple converters are needed to transform the main battery's voltage to a higher voltage level to drive the traction motor in addition to 42 volts and 14 volts for accessory loads. By integrating multiple converters, ORNL power electronics researchers have reduced the number of electronic components, enhancing reliability and contributing significantly to the cost reduction and increased power density goals of DOE's Vehicle Technologies Program.

Highly efficient power electronic systems such as ORNL's triple voltage dc to dc converter require less cooling and discharge less battery energy than conventional electric systems. As a result, more battery energy is available, enabling an electric car to accelerate faster and travel a longer distance before the battery must be recharged and helping make advanced vehicles more appealing to consumers.

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Sponsor: DOE EERE Vehicle Technologies Program

Plug-in Hybrid Electric Car Evaluated

In February and March 2010, Jeff Christian, a researcher with ORNL's Buildings Technologies Research and Integration Center, drove a plug-in hybrid electric vehicle (PHEV) between ORNL and the most energy-efficient test house in Knox County's Campbell Creek subdivision. He monitored the test house's energy management abilities at work and the fuel-use efficiency of the Toyota Prius PHEV over each 16-mile, one-way commute.

He found that the PHEV's fuel economy ranged up to 102 miles per gallon (MPG). The gasoline cost per mile for the PHEV was about 4 cents, roughly half that today for a regular car getting 30 MPG.

Christian used the house's dedicated electrical plug to "smart charge" the PHEV's Hymotion A123 lithium-ion battery five times a week between 8 p.m. and 3 a.m. using ~3 kilowatt hours of off-peak electricity. The Tennessee Valley Authority (TVA) is interested in comparing the load factors—average power divided by peak power over time—of its three Campbell Creek research houses: a builder house, a retrofitted house, and a test house built to generate almost as much electricity as it consumes through photovoltaic (PV) solar panels connected to TVA's Generation Partners grid.

Compared with the builder house, the PV house consumed 60 to 70% less electricity for a cost of just $37 a month, but its load factor was no better. When the battery charger raised nighttime power demand, the PV house's load factor exceeded that of the builder house. Christian believes integrating high-performance houses with charging stations could make residential load factors more favorable to TVA and the 158 distributors.

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Sponsors: DOE Building America Project, DOE Office of Electricity Delivery and Energy Reliability, TVA

Jeff Christian explains the advantages of a Toyota Prius plug-in hybrid electric car to middle-school children during National Laboratory Day at ORNL on May 5, 2010.

Corrosion and Wear Resistant Coating for Geothermal Drills

When Bill Peter joined ORNL in 2004, he worked with Craig Blue and others to transform a noncrystalline (amorphous or glasslike), iron-based powder into a crystalline coating that makes cutting surfaces amazingly hard and wear resistant.

In 2008 ORNL researchers deposited the coating on steel disc cutters used by a huge Herrenknecht tunnel boring machine to cut through rock to make tunnels in mountains for sewage overflows (Atlanta, Georgia) and a highway (through Switzerland's Alps to Italy). The ORNL coating extended the life of the disc cutters by 20 to 30%.

Using a laser fusion technique on a powder made from an iron-containing bulk amorphous glass and encapsulated in a polymer binding, Peter showed that rapid heating and cooling at thousands of degrees per second had multiple effects on the coating and cutter material. The pulsating laser light changed the noncrystalline powder into a nanocrystalline coating on the steel cutter substrate; created a metallurgical bond between the coating and substrate; heated the coating and top substrate layer beyond the melting temperature, causing convective stirring and an alteration in the coating chemistry; and allowed the material to cool rapidly, preventing the fine crystalline grains from coarsening. The high cooling rate produced a nanocrystalline composite coating with high wear resistance.

"Our technique developed a surface layer that is 2 to 7 times harder than the steel substrate with up to 10 times improvement in abrasive wear resistance," Peter said. Now, the ORNL research group is investigating other possible applications for the coating. One potential use is to coat conical mining bits and other tools for rock crushing to expedite highway construction. Another is to coat a steel drill bit for boring a hole in the ground to develop a geothermal well, a renewable source of hot steam that can turn a turbine to generate electricity.

The coating for the geothermal application must be highly resistant to corrosion deep in the ground where bromides and chlorides are present. The goal is to prevent coatings that confer hardness from corroding away in such a chemically harsh environment.

In a work-for-others project, ORNL researchers collaborated with Carpenter Technologies, which synthesized 12 tons of bulk amorphous steel powder for ORNL experiments. The product is an iron-based powder laced with plenty of carbon and boron.

When ORNL researchers consolidated some of the powders to solid state rather than melting them, the powders devitrified—shifted from the amorphous state to the nanocrystalline state. The nanoprecipitates of carbides and borides were uniformly dispersed. Melting the powder would have resulted in uneven segregation of the carbide and boride particles rather than a homogeneous distribution that makes the material uniformly hard.

To improve the corrosion resistance of the coating for geothermal applications, Peter and his colleagues found that the trick lies in tweaking the chemistry with laser fusion. "Because the blank slate is amorphous, we have dialed in the desired nanocrystalline structure," he said. "In 2004 we discovered that when iron powders stay amorphous, the resultant coating is as corrosion resistant as C22, an expensive nickel alloy."

Later, the researchers shifted the chemical composition so that powders of austenitic steel instead of ferrite steel are formed, increasing the corrosion resistance of the resultant coating. Now, they work with Carpenter Powder Technologies on these projects to find chemistries that obtain the highest yields to reduce costs, think of applications, and identify end users that might be interested in iron-based compositions that laser fuse well with steel substrates vulnerable to wear.

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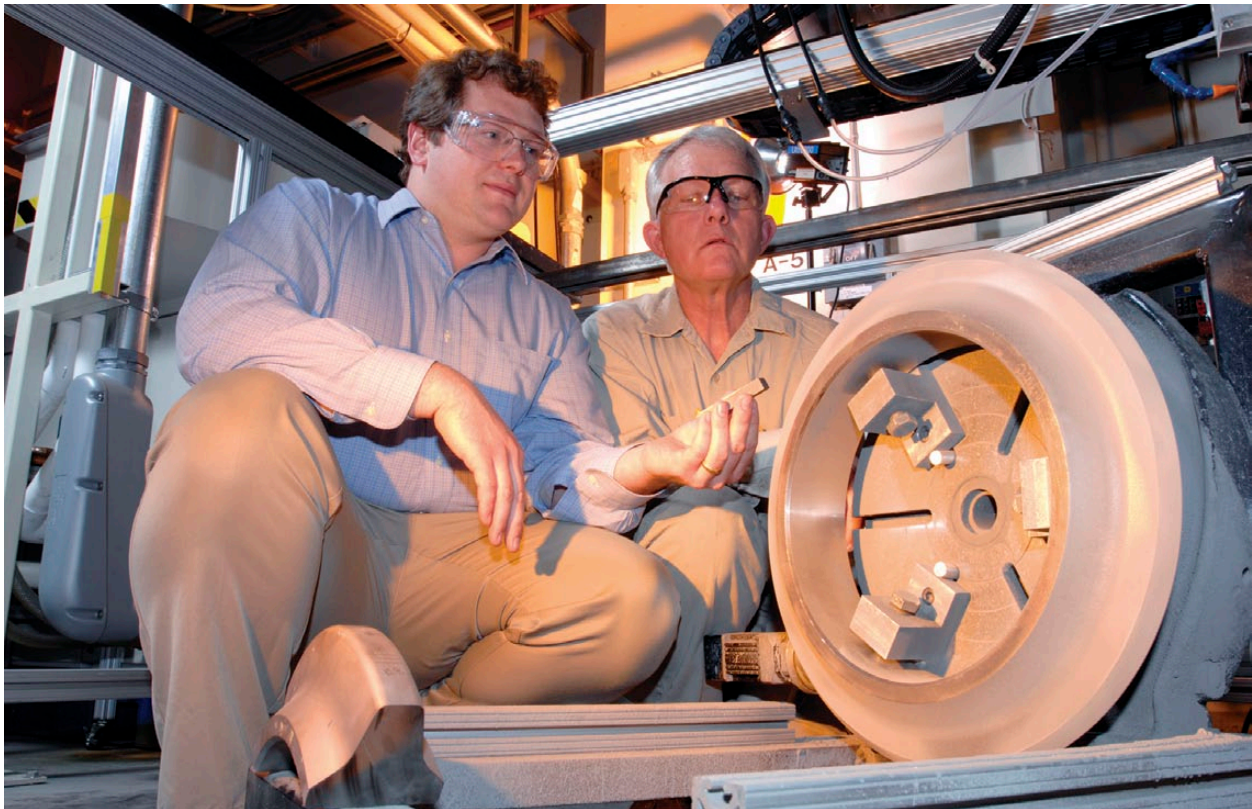
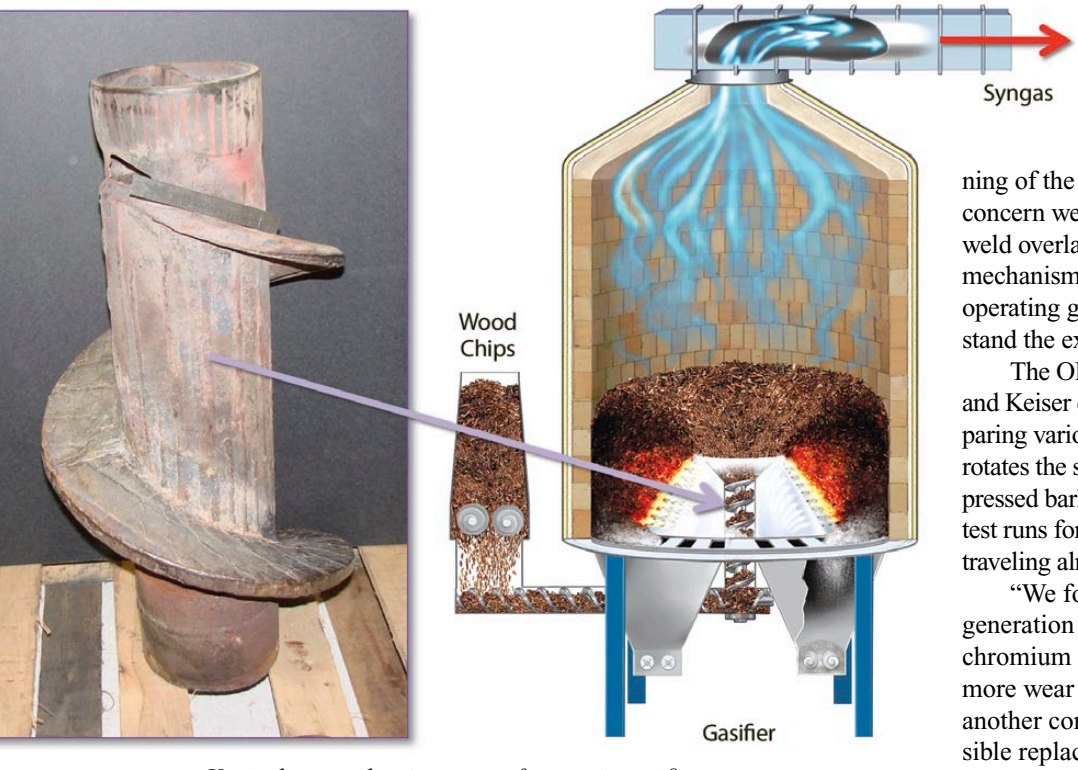
Sponsors: Defense Advanced Research Projects Agency; DOE Office of Civilian Radioactive Waste Management; DOE EERE Vehicle Technologies, Industrial Technologies, and Geothermal Technologies Programs; Work-for-Others projects.

Bill Peter and technician Ed Hatfield examine an ORNL-coated disc cutter for a tunnel boring machine. Peter is holding a sample coupon that has been coated using a technique he helped develop.



Materials Solutions for Biomass Gasifiers



Vertical auger showing wear after use in gasifier

Using biomass to produce a fuel gas is one way ORNL can reduce its carbon footprint. Johnson Controls is converting the ORNL central campus steam plant, which once burned coal and now burns natural gas, into a facility that will heat and gasify wood chips made of waste from sawmills, pallet manufacturers, and tree-trimming operations. The ORNL biomass gasifier will provide hot gas to heat water, producing steam for warming and cooling building interiors.

Nexterra, a small company in Vancouver, British Columbia, Canada, has commercialized its gasifier concept for producing syngas, a mixture of hydrogen and carbon monoxide that is burned in an oxidizer to produce steam or hot water. Nexterra gasifiers are currently in operation at several locations, including two at a wood veneer plant in British Columbia and three at the University of South Carolina.

Jim Keiser, a researcher in ORNL's Materials Science and Technology Division, has been investigating materials problems encountered in these facilities. Using ORNL internal funds, he is applying the insights gained from these investigations, along with the results of studies conducted at ORNL, to help Nexterra and Johnson Controls address these materials problems. The goal is to use the solutions identified to help avoid many of these problems when the wood gasifiers are turned over to ORNL in January 2012.

The Nexterra gasifiers in both locations have required more frequent replacement of the vertical augers used to lift wood chips into the gasifier than anticipated annually. An auger cannot be replaced without shutting down the gasifier, resulting in a loss of production.

These augers are constructed of carbon steel with an approximately 1/8 inch thick weld overlay on the wear surfaces that provides some resistance to degradation by the wood chips sliding over the surface. "The tops of the vertical augers that lift wood chips into the Nexterra gasifiers showed severe, localized thinning of the central pipe," Keiser said. "Of particular concern were the cracking and spalling of the augers' weld overlays." In an effort to determine the failure mechanism and the frequency, Keiser visited all the operating gasifiers during shutdowns to better understand the extent and nature of the degradation.

The ORNL team of Peter Blau, Adam Willoughby, and Keiser designed and built a test facility for comparing various weld overlay materials. The test system rotates the samples through a bed of warm, moist, compressed bark normally used for home landscaping. Each test runs for 300,000 revolutions—the equivalent to traveling almost 180 miles through an abrasive medium.

"We found that Nexterra's second- and third-generation weld overlays—tungsten carbide and chromium carbide—on carbon steel make the auger more wear resistant," Keiser said. "But we also tested another commercial product, Hardalloy 140, as a possible replacement weld overlay to make the carbon steel even more wear resistant."

Hardalloy 140 is considered an excellent overlay material to protect carbon steel tools subjected to heavy abrasion and moderate impact. In tests conducted at ORNL, the Hardalloy 140 showed less degradation than the other alloys Nexterra tried.

Keiser and his colleagues have internal funding to solve the materials problem of auger weld overlays to help Johnson Controls, which will install three Nexterra wood chip gasifiers next to the old steam plant at ORNL by early 2012. With assistance from ORNL researchers, the gasifier augers should have the longevity and reliability that ORNL management expects.

Contact: Jim Keiser, 865-574-4453, keiserjr@ornl.gov

Sponsor: ORNL seed money

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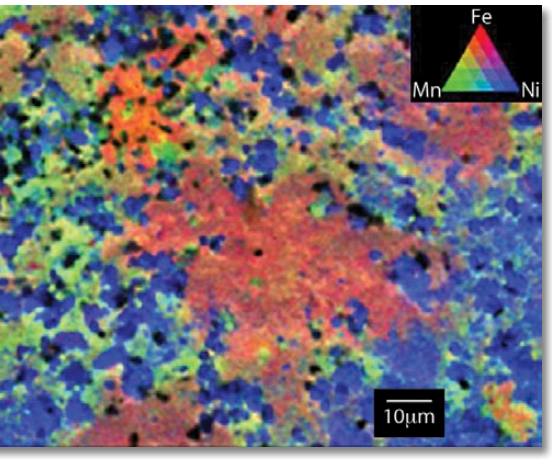
Success Stories at the High Temperature Materials Lab

Building on characterization research at ORNL's High Temperature Materials Laboratory (HTML) on the effects of exhaust gas on microturbine recuperators—which recover heat from the gas to preheat pressurized air to improve efficiency—***Capstone Turbine Corporation*** replaced the original 347 stainless steel alloy with the HR-120 alloy. Tests showed that HR-120 increased the life of the recuperator core to ~80,000 hours. Since this research, Capstone has developed a product line of durable microturbines for vehicles and power generation. For example, during product testing on a fleet of 150 demonstration buses in New York City, ECOSaver IV hybrid vehicles manufactured by DesignLine (Charlotte, N.C.) and equipped with Capstone turbines consumed 50% less fuel than the traditional diesel bus fleet, for an annual fuel savings of up to 6,000 gallons per vehicle. The harmful emissions of the hybrid buses are much lower than those of traditional buses. In addition, Capstone turbines operate within the U.S. Environmental Protection Agency and California Air Resources Board 2010 limits for heavy-duty engine emissions without the need for any exhaust after-treatment.



Elemental mapping of an HR-120 alloy recuperator core sample showing mixed oxides of iron, manganese, and nickel.

In another HTML User Program project, Capstone in partnership with United Technologies developed a microturbine-chiller combination that produces electricity and chilled water with up to 90% total system efficiency. The Ronald Reagan Presidential Library in Simi Valley, California, selected this technology for onsite generation of electricity and later reported utility savings of $380,000 per year.

GEO2 Technologies, LLC, a Massachusetts start-up firm, has developed a diesel particulate filter material with a unique, proprietary, fibrous, cross-linked microstructure. Mechanical properties testing at the HTML demonstrated that GEO2's substrates are much more crack-resistant than other commercially available products. Remarkably, these substrates exhibit high fracture toughness even with high values of porosity, a difficult achievement. In addition, the fibrous substrates capture more than 99% of combustion-generated particles. GEO2 is licensing this technology. Expected benefits are lower emissions from diesel engines as a result of greater engine efficiency from reduced back-pressure and also job creation as the firm expands manufacturing capability to meet demand.

Tim Gordon of GEO2 Technologies sets up a fracture mechanics test.

Metalsa supplies side rails and chassis components to more than half of the North American heavy truck market. Metalsa came to HTML's neutron scattering residual stress mapping facility at the High Flux Isotope Reactor to measure and map residual stresses that result from four different hole-cutting methods. Residual stresses are important because they can be a major factor in fatigue cracking and product failure. Participation in the HTML User Program at ORNL enabled Metalsa to refine a hole-cutting method for reducing weight by 10 to 20% in several of its current production models. This weight reduction of 100 to 200 pounds per truck for the frame rails alone resulted in an annual steel savings of up to 30 million pounds for Metalsa's customers. Total fuel savings for 150,000 trucks driving 100,000 miles per year is estimated to be 3.8 million gallons each year.

Engine bearings delivered from a factory to ***Caterpillar, Inc.***, developed a reddish brown stain on the bearing face that appeared to be a dried residue. These bearings were rejected by Caterpillar's quality assurance inspectors and its dealers, causing a parts shortage and lost revenue of nearly $2 million. Caterpillar researchers sought help from the resources at HTML through the HTML User Program. The researchers performed expanded X-ray diffraction scans of the bearing stains. The scans revealed the presence of lead formate hydroxide, a product of the reaction between a carbonate in the final rinse water and lead in the bearing. Experiments showed the residue would not form if distilled or deionized water were substituted for the relatively hard process water. Caterpillar instructed the vendor on how to alter the final rinsing process to correct the problem.

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Sponsor: DOE EERE Vehicle Technologies Program

Honors and Awards

Michael Santella, a researcher in ORNL's Materials Science and Technology Division (MSTD), and **Robert M. Wagner**, acting director of the Fuels, Engines, and Emissions Research Center at the National Transportation Research Center, have been named winners of the 2010 Forest R. McFarland Award by SAE International, a global association of engineers and technical experts in the aerospace, automotive, and commercial vehicle industries. The McFarland award recognizes individuals for outstanding contributions to the SAE Engineering Meetings Board and to the development and distribution of information through technical meetings, conferences, and professional development programs.

Robert M. Wagner

Michael Santella

Of the eight R&D 100 Awards that ORNL researchers won in 2010 from *R&D* magazine, which recognizes the 100 most significant innovations of the year, two have relevance for advanced electric vehicles and transmission of electricity. They are Sulfur-Carbon Nanocomposite Cathode Material and Additives for Lithium-Sulfur Batteries, developed and submitted by **Chengdu Liang** of ORNL's Center for Nanophase Materials Sciences, and **Nancy Dudney** and **Jane Howe**, both of MSTD; and High-Performance, High-T_c Superconducting Wires Enabled via Self-assembly of Nonsuperconducting Columnar Defects, developed and jointly submitted by SuperPower Inc., the University of Houston, and the University of Tennessee with ORNL researchers **Amit Goyal, Sung-hun Wee, Eliot Specht, Yanfei Gao, Karren More, Claudia Cantoni, Keith Leonard, Malcolm Stocks, Tolga Aytug, Mariappan Parans Paranthaman, David Christen, Jim Thompson**, and **Dominic Lee**.

Chengdu Liang, Nancy Dudney, and Jane Howe

Mariappan Parans Paranthaman, a chemist in ORNL's Chemical Sciences Division, has co-edited a book, *High Temperature Superconductors*, published by Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim (ISBN: 978-3-527-40827-6). This research and professional reference and teaching tool provides the most comprehensive presentation of state-of-the-art research in the field of high-temperature superconductors, now being commercialized for power delivery devices, such as transmission cables, motors, and generators.

The paper by **Kai Wang**, Energy and Transportation Science Division (ETSD), entitled "Review of Secondary Loop Refrigeration Systems," was selected as one of the "Top 25 Hottest Articles" from the *International Journal of Refrigeration*.

Pat Love (ETSD) received an award of excellence from the Society for Technical Communication's Chicago Chapter for her pop-up brochure "A New Kind of Bragging Rights: Builders Challenge." The brochure, seen by thousands at Builders Challenge exhibitions, contains information for builders and home owners about DOE's EnergySmart Home Scale (E-Scale) developed to help home buyers compare, and builders communicate, energy efficiency values.

The Amit Goyal team

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News Briefs

Cooling LEDs with Graphite Foam

Largely because of its ability to remove heat from and extend the life of light-emitting diode (LED) lamps, ORNL's carbon foam technology has been licensed to LED North America. The agreement was signed August 27, 2010, by LED North America's Andy Wilhelm and ORNL Director Thom Mason.

LED North America, located in the Tech 2020 business incubator in Oak Ridge, intends to use lightweight graphite foam to passively cool components in LED lamps, which are increasingly in demand for street, traffic, and parking garage lights. Graphite foam–cooled lights will soon be installed at the Heritage Center, a business park at East Tennessee Technology Park in Oak Ridge.

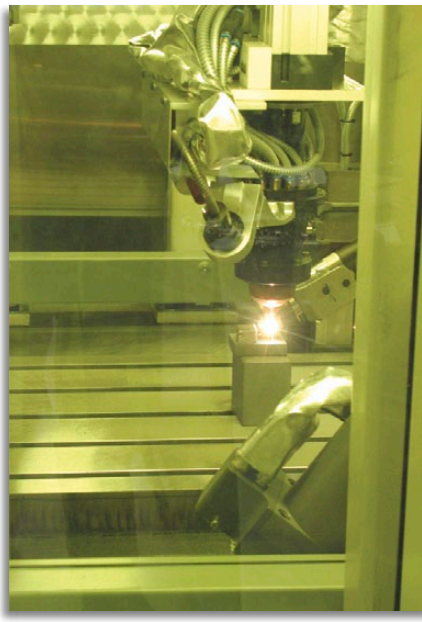
Since each 10-degree decrease in temperature can double the life of LED lighting components, cooling LED lamps is critical to increasing their efficiency, which exceeds that of conventional lights. Using graphite foam to dissipate the heat of LEDs more rapidly than can copper and aluminum could help extend the life and lower the cost of LED lamps, making the technology more attractive to a broader consumer base.

James Klett, the inventor of the patented graphite foam manufacturing technology and a researcher with ORNL's Materials Science and Technology Division, said, "Although this technology will reduce temperatures and increase the life of LED lighting systems, its chief benefit to municipalities should be lower costs of maintaining and replacing light fixtures."

Graphite foam can dissipate so much heat from LED lights that it significantly increases their life.

Direct Manufacturing Equipment Installed

Several staff members of the Industrial Technologies Program (ITP) at ORNL have completed installation of three pieces of state-of-the-art equipment for direct manufacturing of components from powdered-metal feedstock such as titanium. The equipment, purchased with capital funding from DOE ITP, positions the laboratory as a world leader in direct manufacturing R&D. That means ORNL has the ability to use a computer model that guides rapid fabrication of components with an optimized design from consolidated metal powders, increases the fabrication process's energy efficiency, and reduces its material waste.



ORNL's new ultrasonic consolidation unit manufactured by POM Group, Inc., will be used to show the feasibility of making advanced heat exchangers by consolidating titanium powders.

Ultrasonic consolidation of powders enables the development of advanced heat exchangers and the precision incorporation of optical fibers into materials to create sensing devices. Electron beam melting makes possible the formation of low-cost titanium powders into components or sheets for the biomedical, automotive, and aerospace industries. Laser metal deposition enables the development of low-cost coatings that provide substrates with superior resistance to corrosion and wear.

"This type of R&D is expected to have a major impact on energy efficiency in manufacturing," said Craig Blue, manager of ORNL's Energy Materials Program.