Science & Technology HIGHLIGHTS

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Ramping Up ORNL–Industry Interactions

The industrial sector accounts for nearly one-third of the U.S. economy and nearly one-quarter of the products of global manufacturing. Industry drives the U.S. economy, providing the jobs, raw materials, and finished products that Americans need.

The Department of Energy's (DOE) Industrial Technologies Program (ITP) in the Office of Energy Efficiency and Renewable Energy (EERE) is working to preserve the U.S. lead in manufacturing. ITP connects innovators of technologies with interested manufacturers to ensure world-class technology and products. The technologies are further adapted for real-world applications with funding from DOE and industry, which covers 20 to 50% of the cost. The buy-in of industry makes technology transfer successful and profitable.

"ORNL received $29.7 million in American Recovery and Reinvestment Act (ARRA) funding in fiscal-year 2010, to work closely with industry to develop and deploy advanced materials technology," said Craig Blue, director of the Energy Materials Program at ORNL. Blue heads an ambitious program for attracting industrial partners to help launch ORNL's industrial and energy materials technologies as commercial products.

ITP plans to establish an integrated facility to enable university and industry leaders to work as a team in the development of technologies using advanced materials processing and manufacturing technology. This facility will assist DOE in achieving its goals of reducing both energy intensity and environmental impacts of manufacturing systems in a cost-effective manner.

"Our goal is the development of industrial collaborations in advancing photovoltaics (PV), lithium ion batteries, novel stainless steels, thermomagnetic processing, and nanomanufacturing," said Blue. "We want to encourage industry to work with ORNL to further develop our advanced materials and materials processing technologies to generate new commercial products."

Alan Liby, deputy director of the Energy Materials Program, said, "The 31 projects we are involved with are in partnership with industry. Every project aims at marrying the practical needs of specific industrial companies with ORNL's range of capabilities. Each company must be willing to bring its own resources to the table and partner with us in a way that leverages DOE's investment to create the outcome we all want, including joint patents, published scientific papers, and improved processes and materials on the plant floor that will create jobs while reducing energy intensity and emissions." For example, in research to develop less expensive, more reliable lithium ion batteries, ORNL and several industrial firms have four cooperative research and development agreements (CRADAs) and two large work-for-others projects. Every single one of those projects has one or more industrial partners.

ORNL will work with PV manufacturers to lower energy intensity while increasing collection efficiency. It is envisioned that ORNL will work with companies in first-, second-, and third-generation PV, using advanced characterization and processing technologies. ORNL researchers are working to establish partnerships with at least six companies. Public solicitation of proposals from companies interested in joining ORNL in PV research and technology projects is the first step toward winning funding from both industry and DOE. This funding may enable the establishment of a solar PV materials integrated facility at ORNL, a critical component to the proposed translational research effort.

"We are leveraging ORNL's Industrial Technologies Program with the Vehicle Technologies Program," Blue said. "The synergy possible between the two programs has been very productive and will help the economy, as demonstrated in ORNL's carbon fiber and lightweight materials work."

For example, ORNL is working with Magnesium Elektron North America (MENA), the sole U.S. fabricator of magnesium sheets needed for building lightweight cars. ORNL's materials researchers are improving microstructure with shear rolling to improve the formability of magnesium components. The goal: To increase the competiveness of MENA's magnesium sheet, improve vehicle fuel economy, and reduce emissions.

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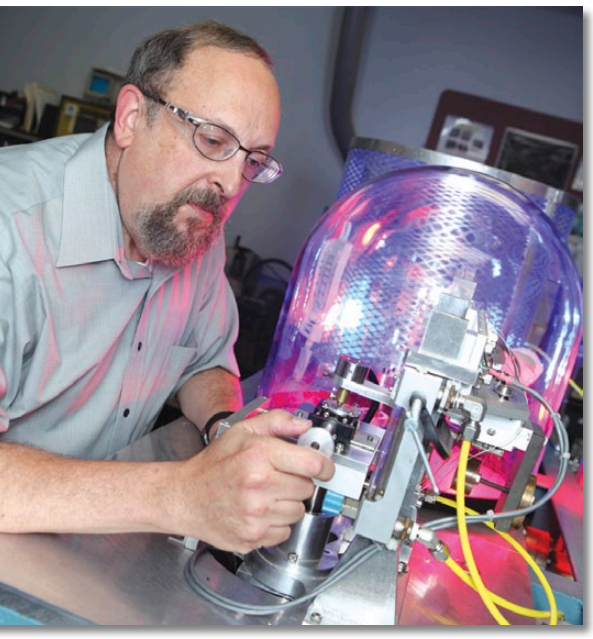
Sponsor: DOE EERE Industrial Technologies and Vehicle Technologies programs

The U.S. manufacturing sector is responsible for the production of airplanes, cars, trucks, ships, trains, chemicals, refined petroleum fuels, iron and steel, other metals and alloys, forest products, plastics and rubber, processed foods, supercomputers, and data storage devices.

ORNL, Industry Collaborate on Vehicle Battery Research



Peter Blau uses a reciprocating tribometer to measure the friction forces between battery materials during repeated charging and discharging.

Increased electrification of transportation is one way to reduce U.S. dependence on imported oil. But replacing cars on gasoline and buses on diesel fuel with plug-in hybrid electric and all-electric vehicles raises this question: "Must America import lithium ion batteries from China, Japan, and South Korea, which lead the United States in the production of batteries for electric vehicles?"

To help make American battery manufacturers more competitive and able to export advanced lithium ion batteries, ORNL is collaborating with American industry to meet some of the most critical challenges facing lithium ion battery production. The new collaborations total $6.5 million.

After receiving $3 million in American Recovery and Reinvestment Act (ARRA) funding in August 2009 through the DOE EERE Industrial Technologies Program (ITP), ORNL issued a competitive solicitation to industry for proposals addressing key problems with lithium ion battery manufacturing science, advanced materials processing, quality control, and processing scale-up. An independent council comprising ORNL and DOE representatives selected five proposals from diverse industries across the country.

Kevin Rhodes uses an x-ray diffractometer to evaluate changes in battery materials during charges and discharges.

"While high-performance lithium ion batteries are projected to be an energy storage "leapfrog" technology, their safety, service life, and costs are still concerns," said ORNL Director Thom Mason. "Forging synergistic collaborations between government and industry will help uncover the solutions that can advance battery technology and lead to stronger national energy security."

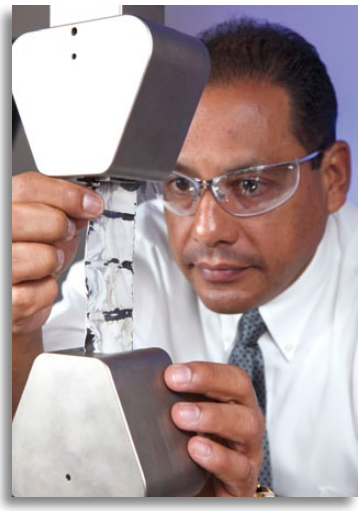
Four companies will match ARRA funding with a total of $2.5 million in cost-share contributions. The companies selected and their project focuses include: A123 Systems, domestic supply of anode materials; Dow Kokam, processing and characterization of novel cathodes; Porous Power Technologies, improved separator between electrodes using a direct coating technology; and Planar Energy Devices, scalable processing for solid-state batteries. Planar Energy Devices, a licensee of ORNL's thin-film battery technology for small devices, is now focusing on developing automotive thin-film batteries.

"By leveraging our expertise in materials science and manufacturing, ORNL will assist these partners with their individual energy storage challenges and address opportunities to surpass non-domestic secondary battery manufacturers that dominate today's market," said Craig Blue, director of ORNL's Energy Materials Program. Secondary lithium ion cell manufacturing encompasses formulation chemistry, film casting, polymer processing, materials and composite design, interfacial science, and component engineering.

In addition to ITP and industry funding, EERE's Vehicle Technologies Program (VTP) is contributing $500,000. Through ORNL's Energy Partnerships Program, the Michigan Economic Development Corporation (MEDC) is providing an additional $500,000 to ORNL for complementary R&D that will support the efforts of Dow Kokam, A123 Systems, and Johnson Controls.

"Funding of one million dollars from VTP and MEDC symbolizes the DOE-Michigan shared goal to achieve full drive train electrification," said Ray Boeman, ORNL program director for Energy Partnerships, who is working in Michigan and Washington, D.C. "With unemployment rates in Michigan among the highest in the country, project successes could promote substantial job growth in the state's automotive sector."

Each of the four companies' proposals supports the automotive supply chain; two companies are installing automotive lithium ion battery manufacturing lines in Michigan. ORNL researchers are working with the companies to solve production line problems, such as low yield and high scrap rates.



Edgar Lara-Curzio uses a mechanical testing machine to characterize the stress-strain responses of various battery materials.

Johnson Controls is collaborating with ORNL on quality control of electrode processing under a work-for-others agreement and also is installing a battery manufacturing line in Michigan.

Other collaborative projects include developing processes for producing electrodes and electrolytes from nanoscale materials; examining performance-limiting, electrolyte-electrode interactions (e.g., formation of nonconductive solids) in a lithium ion battery operating in an electron microscope; understanding how these interactions chemically and mechanically degrade battery performance; and devising a diagnostic tool to monitor battery health and guide battery fabrication.

ORNL's David Wood, co-principal investigator and technical lead on the project, said, "This is a unique and timely opportunity for ORNL to help government and industry set the course for a new generation of energy storage technologies."

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Sponsor: DOE EERE Industrial Technologies, Vehicle Technologies, and ARRA programs

Solar Materials Stimulus

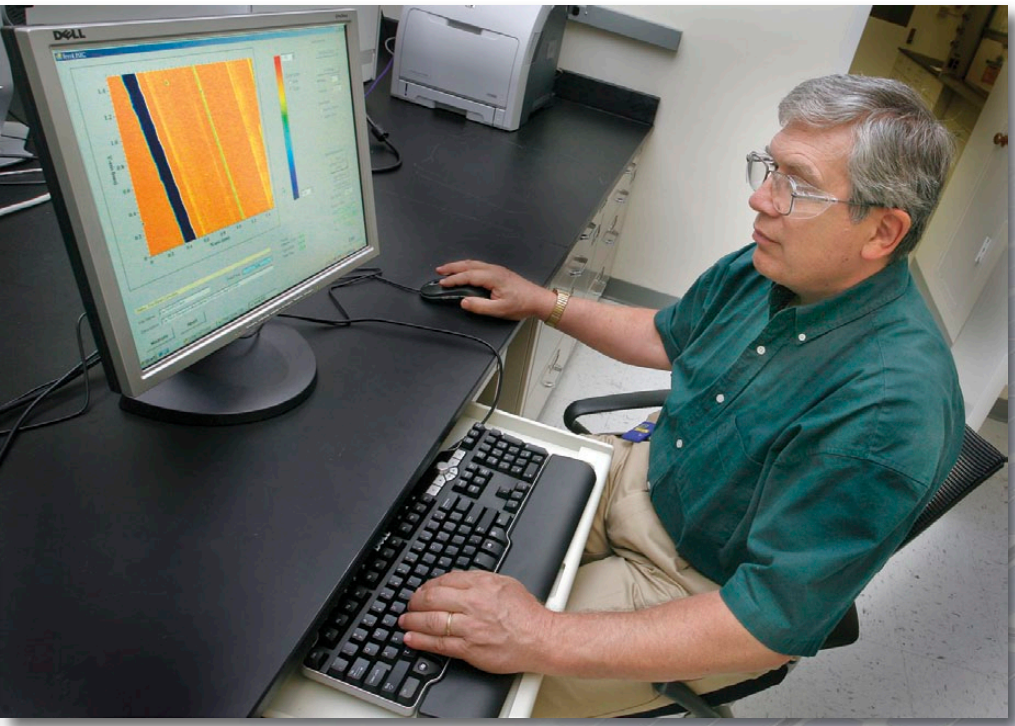
Thin-film solar cells that cost less and perform with improved efficiencies may result from recent stimulus funds from the U.S. government. ORNL's Solar Technologies Program has received $3 million in American Recovery and Reinvestment Act (ARRA) funding through DOE's Office of Energy Efficiency and Renewable Energy (EERE) Industrial Technologies Program (ITP). Chad Duty, program manager, said this flow of funds will help ORNL address fundamental material and processing challenges faced by the U.S. solar industry.

ORNL has an interest in two of the primary materials used for thin-film solar cells: cadmium telluride (CdTe) and copper indium gallium (di) selenide (CIGS). Both CdTe and CIGS solar cells can be manufactured with 10 to 12% efficiency in converting the energy of sunlight to electricity, but the theoretical maximum is 30%, so there is plenty of room for improvement.

"We are buying a sputtering system that uses physical vapor deposition to heat a target and deposit a photovoltaic layer of cadmium-telluride on a substrate," Duty said. "This process is similar to the method by which a thin layer of metal is deposited on plastic formed into a potato chip bag."

The Solar Energy Technologies Program also has purchased a roll-to-roll inkjet facility to demonstrate rapid deposition of conductive inks on a plastic substrate. A new barrier testing facility will measure the rate at which water vapor penetrates a protective barrier coating and condenses on thin-film CIGS solar cells, reducing their ability to absorb energy from the sun.

The ARRA money is enabling the purchase of capital research equipment that will provide insights on how to manufacture highly efficient photovoltaic materials with high throughput and high volume at low cost. Jay Jellison of ORNL's Center for Advanced Thin-film Solar cells (CATS) laboratory is using a variety of tools to measure solar-cell characteristics to improve cell performance. A new quantum efficiency system obtained with ARRA funds will be used to characterize defects in thin-film solar cell materials that reduce the efficiency of the devices.



Jay Jellison studies a visualization of a light-beam-induced current image from a polycrystalline silicon solar cell. A focused laser beam (3 micron diameter) is used to "photoexcite" electrons, which are then collected. Efficient regions of the cell are shown in orange, while green and blue highlight regions of lesser efficiency. This experiment is used to quantify spatially resolved improvements in solar cell performance as a result of heat or chemical treatment.

At the High Temperature Materials Laboratory at ORNL, researchers use multiple instruments to examine in detail the grain structure of CIGS films, including defects that stop electrons. "The goal is to relate structural differences to performance efficiency," Duty said.

To stimulate commercialization of solar technologies, ORNL and several companies are collaborating on improving solar materials processing to make solar panels more efficient and more affordable.

Using the latest-generation plasma arc lamp, ORNL researchers led by Craig Blue developed pulse thermal processing (PTP) for high-speed heating of heat-resistant materials deposited on plastic and paper substrates without changing the substrate temperature. PTP can heat a thin film at a rate of 600,000°C/s over large areas and can pulse on the order of milliseconds or microseconds.

The Solar Energy Technologies Program has worked with the following companies on various projects: Unisolar—crystallizing amorphous silicon on a metal foil substrate using PTP; General Atomics—depositing low-cost thin films of polycrystalline cadmium-telluride on a proprietary substrate; and Ascent Solar—texturing CIGS nanocrystals on a polymer substrate and enhancing its grain boundary refinement, which has been found at ORNL to increase CIGS thin-film efficiency by 50% after the deposited material was rapidly heated by PTP.

Ampulse, Inc., has licensed technologies from ORNL and the National Renewable Energy Laboratory to enable the production of flexible epitaxial photovoltaic films. Ampulse licensed ORNL's method for fabricating high-temperature superconducting tapes. Ampulse's goal is to leverage these technologies to develop and mass-produce highly efficient, low-cost photovoltaic films deposited on flexible single-crystal-like substrates.

Because of ORNL's successes in collaborating with companies on photovoltaic projects, Duty has been asked to plan for the development of a solar energy research user center at ORNL.

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Sponsor: DOE EERE Industrial Technologies and ARRA programs

Carbon Fiber Technology

Reducing the weight of a car is the most practical way to increase vehicle fuel economy and slash greenhouse gas emissions. For every reduction in weight by 10%, a car will increase by 5 to 8% the miles it travels for the same input of energy to the wheels. The weight of an internal combustion engine vehicle, electric car, or plug-in hybrid electric vehicle (PHEV) could be reduced by up to 60% if most of the steel and other materials used to make the vehicle body and chassis were replaced with carbon-fiber composites.

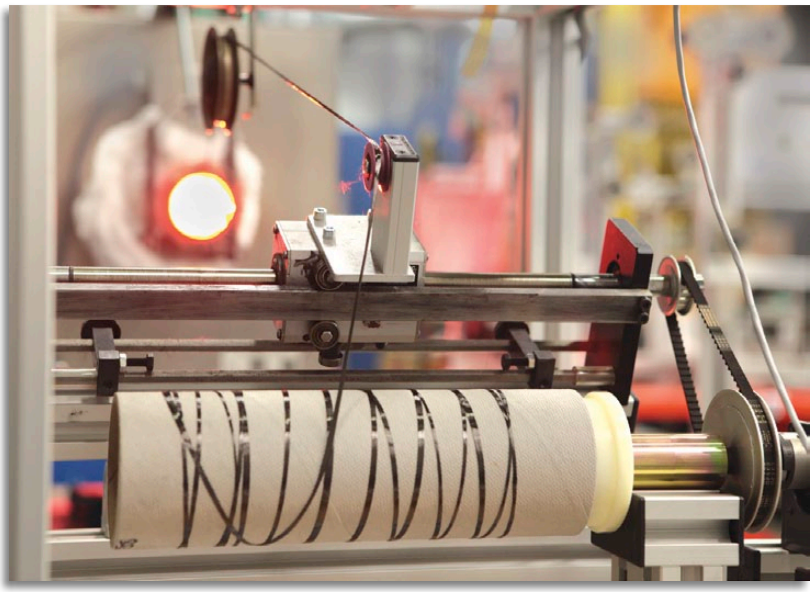
Convincing the major auto companies to switch from steel to carbon-fiber composites has not yet been easy. ORNL tests and computer models have shown that, in the case of a car collision, carbon-fiber composites will hold up and protect passengers as well as steel. The problem is that the price of carbon fibers runs about $10 to $20 per pound. The auto industry will not consider using carbon-fiber composites as a replacement for steel until the purchase price of carbon fiber drops to around $5 to $7 per pound.

Despite its cost, demand for carbon fiber—a lightweight, high-strength material—has grown considerably over the past two decades. The aerospace industry buys carbon fiber for use in aircraft and spacecraft. The sports equipment industry uses carbon-fiber composites to make high-tech bicycles, fishing rods, racing sail boats, tennis and badminton racquets, and golf clubs.

Researchers observe a tight bundle of carbon fibers (tow) exiting a high-temperature carbonization furnace at ORNL.

Rising demand for carbon fiber is coming from the wind turbine industry, which currently produces and uses turbine blades made of glass fiber; carbon-fiber composites would impart the needed strength, stiffness, durability, and light weight to longer blades capable of increased energy capture.

In 2009 the Department of Energy provided ORNL with $34.7 million in American Recovery and Reinvestment Act (ARRA) funding to build the Carbon Fiber Technology Facility (CFTF) in Oak Ridge. The semi-production-scale, carbon-fiber line for the CFTF will be located at an industrial site of the Community Reuse Organization of East Tennessee, whose mission is to spur economic development on local DOE property. The funding will also enable ORNL to consolidate its carbon-fiber composite research—currently conducted in three widely scattered buildings—at a new on-campus composite materials laboratory.



Finished carbon fiber being spooled

Cliff Eberle, an engineer in the Polymer Matrix Composites Group of ORNL's Materials Science and Technology Division (MSTD), said that the CFTF "will be operational in 2012 and will stimulate interactions with industry. However, the CFTF won't be a traditional user center in which industrial users simply spend a week or more collecting data on a sample using ORNL's sophisticated equipment." Instead, Eberle added, "the purpose of the CFTF is to produce and provide carbon fiber materials to potential users in the quantities they need to do development trials and qualification testing to validate fiber quality. The hope is that new carbon fiber users will commit to purchase orders if we demonstrate the scalability of the technology, and as a result, manufacturers adopt the technology for full-scale production of low-cost carbon fiber for composites."

The CFTF will accommodate a *conventional conversion line* for producing carbon fiber from multiple low-cost precursors, including polyacrylonitrile (PAN), an organic polymer derived from petroleum, and lignin, a sustainable resource material derived from wood and switchgrass.

The CFTF will also have a *melt spin line* that will be used to produce precursor fibers from alternative raw materials, such as lignin from paper mills and from biorefineries that separate lignin from cellulose. The biorefinery at Vonore, Tennessee, will take advantage of technologies developed by the Bioenergy Sciences Center at ORNL and the University of Tennessee to economically break down cellulose into sugars and ferment them to make cellulosic ethanol fuel for vehicles. Sources of cellulose and lignin include switchgrass and wood from fast-growing hybrid poplar trees.

Facility Planned for Oak Ridge

In a melt-spinning process, the fiber-forming precursor is melted and forced through a device with many holes, called a spinneret. The extruded viscous material is cooled, causing it to solidify into long, continuous, aligned filaments, or fibers of about 10 microns in diameter, or one-tenth the thickness of a human hair. Melt spinning is widely used to make nylon, polyester, and other polymeric fibers that are used to make clothing, carpets, and other textile products.

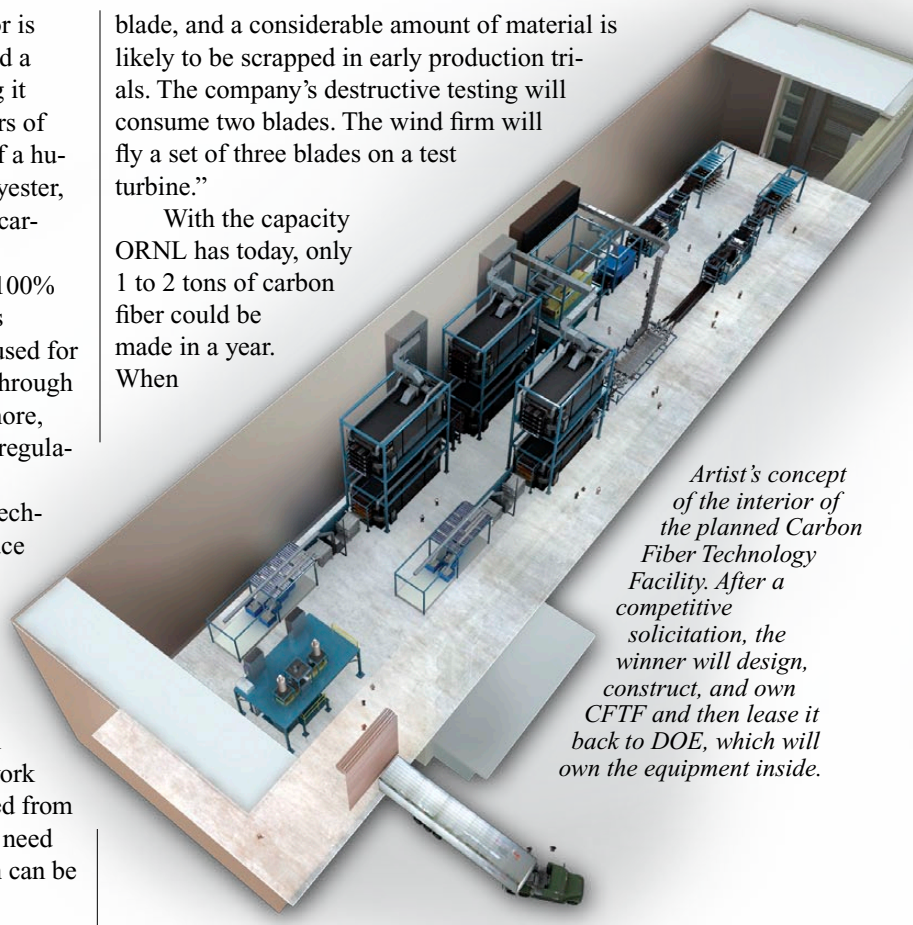
"Melt spinning is cheaper than wet spinning because 100% of the feedstock materials is converted to fiber as they pass through the spinneret," Eberle said. "In solution spinning used for the PAN process, only about 20% of the material passing through the spinneret is PAN, with the rest being solvent. Furthermore, recovering the solvent and complying with environmental regulations make the PAN process costly."

Fred Baker, a scientist in MSTD's Carbon Materials Technology Group, has confirmed that melt spinning can produce a low-cost carbon fiber from lignin. The cheaper the precursor, which usually accounts for half the production cost, the lower the price is for finished carbon fiber.

Baker has spearheaded the development of processes for melt spinning of different types of lignin materials, including the lignin by-product from cellulosic ethanol fuel production in biorefineries. A major breakthrough of this work was the demonstration that high-purity lignin can be isolated from the "black liquor" of the paper-making process without the need for an expensive purification step; even higher-purity lignin can be directly produced from the cellulosic ethanol fuel process.

"We've been working for a decade on the development of new technologies to reduce the cost of carbon fibers," said Eberle. "However, our technologies will make an impact only if they are commercialized. If an auto manufacturer was told that ORNL had developed a low-cost carbon fiber based on lignin, the company might ask for at least one ton a year to determine if high-quality parts for cars can be manufactured from the carbon fiber. A wind turbine manufacturer may ask for 5 to 10 tons of carbon fiber. About 1 ton of carbon fiber is needed to make a single turbine blade, and a considerable amount of material is likely to be scrapped in early production trials. The company's destructive testing will consume two blades. The wind firm will fly a set of three blades on a test turbine."

With the capacity ORNL has today, only 1 to 2 tons of carbon fiber could be made in a year. When the semiproduction conversion line goes into operation in 2012, ORNL will be able to meet demands for up to 25 tons per year of carbon fiber sought by auto and wind turbine companies, as well as other industrial end users, for testing.



Artist's concept of the interior of the planned Carbon Fiber Technology Facility. After a competitive solicitation, the winner will design, construct, and own CFTF and then lease it back to DOE, which will own the equipment inside.

Eberle said that space will be left in the CFTF to install an *advanced technology conversion line* that shows promise in producing low-cost carbon fiber. MSTD's Felix Paulauskas led the development of microwave-assisted plasma (MAP) techniques for eliminating the precursor's nitrogen and hydrogen atoms and lining up the carbon atoms to produce a stiff, strong, graphite-like fiber. MAP techniques can reduce the costs of carbonizing carbon fibers.

"Through its investment in the CFTF, the federal government is facilitating the commercialization of a full-scale manufacturing process for carbon fiber that is cheap enough to be purchased by auto and wind turbine companies," Baker said.

In terms of transportation, ORNL is playing a major role in helping DOE achieve these goals: economically separate cellulose and lignin from wood and switchgrass, convert the cellulose economically into ethanol fuel for vehicles to reduce carbon dioxide emissions, displace petroleum-based fuels, and convert lignin into carbon fiber to reduce vehicle weight and improve fuel economy.

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Sponsors: DOE EERE Vehicle Technologies and ARRA programs

Switchgrass is a source of lignin, which can be used as a carbon fiber precursor. Lignin is an attractive alternative to higher-cost, petroleum-based precursors.

Power Electro

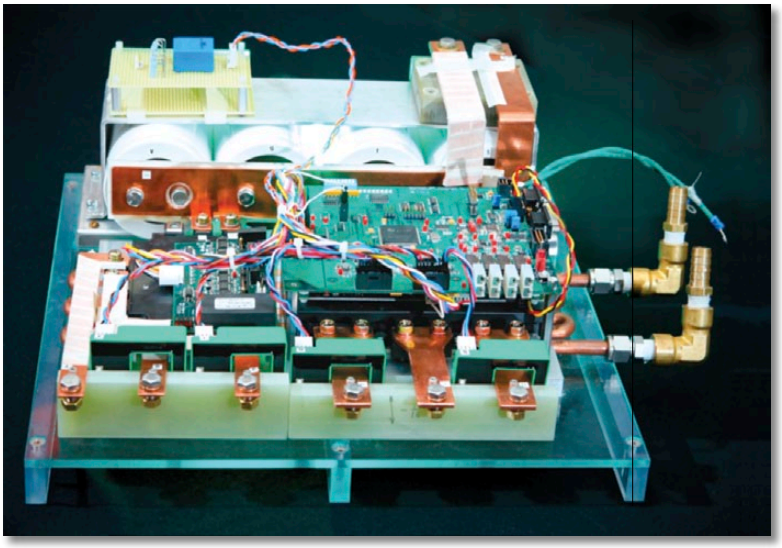
The national drive to reduce both the carbon emissions of vehicles and U.S. dependence on foreign oil suggests that the availability of cars with inefficient, gasoline-powered internal combustion engines will gradually decline. One key to meeting the U.S. goals is to design and manufacture high-performance, electrified vehicles that millions of Americans consider appealing and affordable. Power electronics researchers at ORNL are playing an important role in helping DOE guide the auto industry toward producing electrified vehicles that consumers will buy.

The Power Electronics and Electric Machinery Research Center at ORNL is DOE's broad-based research center charged with helping to lead the nation in the shift from petroleum-fueled vehicles to hybrid-electric and plug-in hybrid electric vehicles (PHEVs). The center's efforts directly support DOE's Vehicle Technologies Program (VTP), the center's funding agency. VTP's goals are to provide Americans with greater freedom of mobility and energy security while lowering vehicle costs and reducing impacts on the environment.

Tapping Hybrid Cars for Power

Future scenario: An ice storm sweeps through your town at dawn, leaving slippery roads and weighted-down tree limbs and power lines, some of which snap. You and your family decide to stay home rather than risk driving your PHEV on hazardous streets. But your car could still be useful.

Suddenly your lights go out, your heat pump stops, and your computer and refrigerator shut down. Anticipating a long power outage, you plug your PHEV into a home outlet and flip a switch, enabling your house appliances to tap the car's charged-up battery for electricity.



This hybrid-electric-vehicle traction drive inverter system developed at ORNL can provide bidirectional plug-in battery charging and mobile power generating capability.

Providing more power than a typical freestanding portable generator, your PHEV can be used in other situations, such as roadside breakdowns and camping. Your PHEV could even power a small business.

When at a charging station, your PHEV could supply power to the grid when demand for electricity has peaked. The charging system could also be used to enhance the voltage stability and efficiency of the grid by providing reactive power.

The local utility could tap your car at the parking lot charging station or in the garage for the real and reactive power it needs and compensate you for the purchased power, reducing your electric bill.

Gui-Jia Su, an innovative electrical engineer at ORNL's Power Electronics and Electric Machinery Research Center, is principal developer of a technology that would make this scenario possible. He and his team designed, fabricated, and demonstrated a PHEV traction drive power electronics system that provides significant mobile power generation and vehicle-to-grid support capabilities.

"Our new technology, which is market ready, eliminates the separate charging mechanism typically used in hybrid electric vehicles, reducing cost, weight, and volume under the hood," said Su. "The PHEV's traction drive system would be used to charge the battery, power the vehicle, and provide electricity to utilities when needed."

The versatile charging system also can give the car battery a slow charge that requires about 8 hours or a fast charge that takes only about an hour. Of course, choosing a fast charge over a slow charge means your electric bill will show a slightly larger charge.

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Sponsor: DOE EERE Vehicle Technologies Program

Wireless Charging

"One fear people have about plug-in hybrid electric vehicles is that they may forget to plug them into their home outlets at night and then find out the next morning that their electric cars have no power," said Laura Marlino, an electrical engineer at ORNL's Power Electronics and Electric Machinery Research Center. "One solution is to install in the garage or carport a rollup wireless charging mat over which your car can park. The mat will wirelessly recharge the car's battery cells."

The mat would be a scaled-up version of the Powermat wireless charging pad now on the market for recharging more than one portable electronic device, such as a cell phone, digital camera, and music player. The PHEV would be fitted with a receiving antenna that runs along the bottom of the car and wirelessly picks up and sends to the battery power transmitted from the antenna embedded in the floor or rolled out as a mat.

Several universities and car manufacturers are developing wireless power pads for various uses. The efficiency of these large experimental pads is about 70%,

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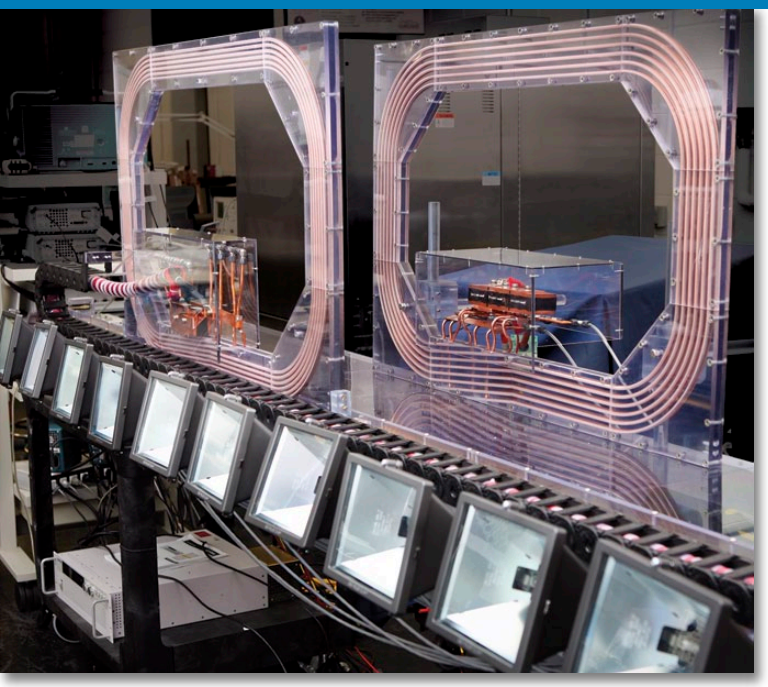

Research prototype of a wireless battery recharging mat for underneath a plug-in hybrid electric car with a receiving antenna running along its bottom. The ORNL apparatus is 90% efficient, whereas other experimental pads are 70% efficient.

whereas the power pad being tested by Marlino's group has an efficiency of 90% as a result of some proprietary technology developed at ORNL.

"Leaders in the power electronics field envision the use of wireless battery recharging pads for PHEVs that are stopped while drivers wait for red lights to turn green," Marlino said. "Drivers will subscribe to a service that will allow them to wirelessly pick up electrical charges at certain intersections. Power pads in lanes by bus stops can be used to wirelessly recharge the batteries of electric buses while passengers climb aboard or exit the vehicles."

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Sponsor: DOE EERE Vehicle Technologies Program

Studying Air-Conditioning Stall

When the temperature outside is above 85˚F, a sudden temporary shutdown of an air conditioning (AC) unit can be uncomfortable. For electric utility managers, the possibility of many such events around the same time is disturbing because of the possible impact on the power system.

To better understand AC stall, which can occur when the supply voltage drops as a result of a short circuit (caused by, say, a falling tree bringing down a power line), ORNL researchers are conducting characterization tests of two heat pumps at the Distributed Energy Communications and Controls (DECC) Laboratory, which has an AC stall test system connected to the ORNL power distribution system. They are working with Southern California Edison and the Western Electricity Coordinating Council to improve understanding of AC stall and to develop better models to characterize the phenomenon.

"The AC stall phenomenon concerns U.S. electric utility managers because it causes microvoltage collapse events in the power distribution system," said Tom Rizy, an electrical research engineer in ORNL's Power Electronics and Electrical Systems Research Center. "The industry is worried that the problem will get worse because of growth in demand for AC, the use of high-efficiency compressor motors that are susceptible to stall, and the ability of nearly simultaneous AC stall events to cause a transmission system voltage collapse that could lead to a cascading power outage."

At ORNL Rizy and colleagues are measuring the relationship between large voltage changes and AC stall. "When the compressor motor of the heat pump or AC unit stops rotating because the voltage suddenly drops, the unit no longer produces conditioned air," Rizy explained. "The compressor motor is designed to operate efficiently at 5% lower or higher than 208 volts, but it is susceptible to stall during low voltage."

For the test heat pump, the researchers lowered the voltage to 60% or less of 208 volts until the AC unit stalled. The control heat pump operated normally at 208 volts without any voltage drop.

"We found that compressor motor stall events last around 5 minutes when the voltage is not restored to 208 volts, ending only when the thermal relay trips off the overheated compressor motor," Rizy said. "After about 3 minutes of recovery, the compressor motor cools and then restarts. We observed that stall and restart result in a higher than normal current draw, lowering the voltage even more."

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Sponsor: DOE EERE Office of Electricity Delivery and Energy Reliability

Tom Rizy, with the variable voltage controller that causes the supply voltage to drop in one heat pump but not the other. The aim of the research is to better understand air-conditioning stall. Inset: heat pump compressors at ORNL's Distributed Energy Communications and Controls Laboratory.

Measurements Under Way at Highly

Many people interested in driving a fuel-efficient car also desire to live in an energy-efficient house that will save them money in the long run through lower utility bills. Highly energy-efficient buildings are also appealing because they provide healthy indoor living spaces and cut back emissions of climate-altering carbon dioxide by reducing the need for electricity from fossil fuel combustion. Furthermore, energy-efficient buildings will slash consumer demand for electricity during periods when the loads on electric utilities are highest, helping utilities avoid purchasing premium-priced power from the wholesale market during periods of peak demand, or building additional power plants to handle the load.

House 1 has structural insulated panels to shelter indoor areas from the weather.

The ZEBRAlliance, which strives to maximize use of cost-effective energy-efficiency technologies, has built four energy-efficient houses in the Crossroads at Wolf Creek subdivision in Oak Ridge. ZEBRAlliance is both a research project and a multi-faceted, education campaign designed to convince consumers that energy-efficient homes can be affordable. The four houses demonstrate different strategies for saving energy but all are about 55 to 60% more efficient than traditional new construction. The houses eventually will be sold to interested homebuyers.

The founders of the public-private alliance are ORNL and Schaad Companies. The sponsors of the initial ZEBRAlliance project include DOE's Building Technologies Program in the Office of Energy Efficiency and Renewable Energy; Schaad Companies, BarberMcMurry Architects, and other ORNL industry partners; and the Tennessee Valley Authority.

The four houses are similar with a few notable differences. Houses 1 and 2 are 3-level buildings with walkout basements whereas Houses 3 and 4 are 2-level structures over crawlspaces. ClimateMaster's high-efficiency, water-source heat pumps and ground loops provide space conditioning and hot water in three houses; however, House 4 has a high-efficiency, Lennox air-source heat pump and GE hybrid electric water heater. The walk-out basement houses use the foundation excavations for placement of the horizontal ground loops whereas House 3 has the more common and more costly vertical borehole ground loop.

Each house contains high-efficiency lighting, Energy Star appliances, and a unique wall system strategically placed near the kitchen, bathroom(s), and laundry and utility room for recovering heat from exhaust air streams and limiting standby losses from hot water lines in each house. All roofing materials have infrared reflective pigments that reflect solar energy from the infrared portion of the spectrum back to the sky, enabling roofs with appealing colors to stay cool and reduce energy use for air conditioning. All windows are triple-pane, low-emittance, gas-filled designs.

"The project provides two sets of side-by-side research houses with identical floor plans, with one set having walkout basements and the other crawlspaces," said ORNL's project manager and building researcher Bill Miller. "In these unoccupied research houses human impact on energy use is simulated to match the national average. About 300 sensors are scattered about each house, and every minute sensor measurements are sent to our data acquisition system, where they are recorded, analyzed, and used to validate our computer simulation models."

"The lights, ovens, washers, and dryers in all four houses go on and off exactly at the same time, and the showers in all four houses are simulated exactly the same way," said ORNL building researcher Jeff Christian. "Simulating the occupancy enables valid side-by-side experiments. For example, one home will be lit with Molex fixtures that use Seoul Semiconductor's award-winning, light-emitting diode (LED) technology. The LED lighting will be compared with state-of-the art compact fluorescent lights in the adjacent house with the identical floor plan, lighting system design, and lighting usage patterns."

All four houses have different barriers, or envelopes, that shelter indoor areas from the weather. House 1 has structural insulated panels (SIPs). Each panel consists of an inner core of insulating foam sandwiched between two outer skins made of oriented strand board (OSB). SIPs enable airtight construction and meet code without the use of structural members such as studs, thereby avoiding thermal short circuits from such components.

House 2 has optimal value framing with oriented strand board sheathing, which is coated to create a weather resistant barrier.

Energy-Efficient Houses in Oak Ridge

House 2 has optimal value framing—stick-built wood framing using 2 by 6 in. studs, 24 in. on center with ½ in. OSB sheathing. Care is taken to align rafters with studs so that even with sparse structural members (traditional framing is 16 in. on center), the framing system satisfies the structural code. Although thermal short-circuiting through structural members remains with this approach, it is reduced by about half. The structure's airtightness is improved by applying a special liquid to the sheathing to create a weather resistant barrier. Walls contain flash and batt insulation, a combination of sprayed foam and fiberglass batts that provides an insulating value of R-21.The cathedral roof is fitted with a foil-faced, phenolic foam board between the rafters, yielding an overall thermal resistance of about R-50.

House 3 uses cellulose insulation with an additional ingredient that enables it to store thermal energy. Talc-like micro capsules containing phase change materials (PCMs) are mixed with the recycled newspaper and adhesives of conventional cellulose (to which a fire retardant is added). The bags of cellulose come from the factory pre-mixed at 20% by weight PCM, and conventional cellulose-blowing equipment is used to install it. The PCM-enhanced cellulose, which absorbs heat during the day and releases it at night, is installed on the attic floor and in the exterior walls. Because PCM-enhanced cellulose is more expensive, the project uses a hybrid insulating approach with conventional cellulose on the indoor side of the attic and walls and the PCM-enhanced material on the outside, where it can naturally self-cool at night. The PCMs are expected to reduce space conditioning costs by up to 25% overall, with peak period savings even higher. This new style of insulation won an R&D 100 Award in 2009 for ORNL researcher Jan Kośny and his industry partners, Microtek Laboratories and Advanced Fiber Technology.

House 3 has an award-winning, fire-resistant, commercial, cellulose insulation mixed with ORNL-developed microcapsules that contain phase change materials.

House 4 demonstrates an advanced exterior insulation finishing system (EIFS), which is self-drying through the use of a layer integrated into the assembly that provides a path for buoyancy or wind-driven air movement and a condensation and drip plane. With EIFS, the insulation wraps around the outside of the frame, avoiding thermal short-circuiting through structural members. In this case 5 in. of expanded polystyrene (EPS) was installed, providing R-20. The new self-drying design by Dryvit Systems, Inc., exhibits outstanding moisture management and includes a flexible, polymer-based membrane applied as a liquid over the plywood sheathing to serve as a weather-resistant membrane and to improve air tightness.

On House 4, the exterior insulation finishing system consists of Dryvit Systems' Outsulation Plus Moisture Drainage System.

Houses 1 and 2 were completed in November 2009, and data collection began a month later. Houses 3 and 4 were expected to be completed in June 2010, with data collection to begin in July. A "Grand Opening Ribbon Cutting Event" for the houses is planned for September 20, 2010. With results already beginning to roll in, educating the building science community, builders, and consumers has become an ongoing process, nationally as well as locally. For example, Kevin O'Connor, former executive producer of PBS's "This Old House," recently filmed inside and outside the ZEBRAlliance homes for 3 segments of the upcoming 13-show TV series "This New House," which is being developed by the Scripps DIY (Do It Yourself) Network. Christian played the role of the mad building scientist and served as host and tour guide for the TV crew.

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Sponsor:DOE EERE Building Technologies Program

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Prototype of the Nissan Leaf electric car at the 2010 Detroit Auto Show

Case Study: Interaction Between Electric Vehicles & Power Sources

ORNL will soon offer an opportunity to employees who elect to drive an electric vehicle (EV) or plug-in hybrid electric vehicle (PHEV) to and from work to recharge their car batteries during work. Charging will be available at a solar-assisted (solar-panel–covered) parking lot and, in selected locations, non-solar-assisted charging stations. By adding energy storage and renewable energy facilities to this grid-connected system, ORNL will gain valuable experience in testing the interactions and determining the most efficient arrangement between each vehicle and various power sources.

While not part of this current project, ultimately power providers may be able to draw power from PHEV and EV car batteries during peak demand hours when air conditioning loads mount, reducing electricity costs. However, PHEV and EV owners would likely expect compensation for providing vehicle-to-grid (V2G) services based on the effects on battery life and shortfalls in anticipated charge levels.

These cost compensation strategies are suggested in a paper authored by a team from the University of Texas at Austin (Yogesh Dashora and J. Wesley Barnes) and ORNL (Rekha S. Pillai, Todd Combs, and Michael Hilliard). The study is titled "Optimized Energy Management for Large Organizations Utilizing an On-Site PHEV Fleet, Storage Devices and Renewable Electricity Generation."

The authors developed a mixed integer linear program to provide optimized energy management scenarios to any organization with a large number of employees working within a small geographic location. The authors chose ORNL for their case study. According to the paper, the case study "produced encouraging results and substantiated the importance of controlled PHEV fleet charging as opposed to uncontrolled charging methods. We further established the importance of realizing V2G capabilities provided by PHEVs because they significantly reduce the organization's energy costs."

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Sponsor: DOE EERE Vehicle Technologies Program

ORNL Work May Enable CHPs to Burn Landfill Gas

The Department of Energy's program to develop and deploy combined heat and power (CHP) systems to significantly improve energy efficiency has undergone two changes since its recent move to DOE's Industrial Technologies Program (ITP). First, ITP is interested in larger CHP, or co-generation, systems for larger industrial applications (> 20 megawatts), as well as the small- (<1 MW) and medium- (1-20 MW) sized CHP systems.

Second, the fuel used by CHP systems will no longer be exclusively natural gas. Both DOE and industry are emphasizing use of lower-quality gas produced by gasifying biomass, such as wood chips and plant oils, as well as landfill gases, which contain methane, carbon dioxide, and siloxane—a contaminant that turns into silica, which wreaks havoc on engine parts.

A CHP system uses a fuel cell or either a reciprocating engine or turbine connected to a generator to provide electrical power. The waste heat is converted into a useful form, such as steam, process cooling, hot water, or additional electricity.

ITP's target is penetration of CHP systems in 20% of commercial and industrial applications by 2030, up from roughly 9% today. ORNL's Patti Garland, currently on assignment at ITP in Washington, D.C., led the preparation of a report for ITP that presents the advantages of a widespread deployment of CHPs for the U.S. energy economy and obstacles that must be overcome to achieve the 20% target.

CHP doubles the effectiveness of the fuel, uses rather than throws away waste heat, provides reliable power on site, makes the building less susceptible to electric grid power interruptions, and supplies power for sale to the grid.

ORNL's current research with industry is directed toward removal of siloxane from landfill gas and mitigation of silica damage to engine parts, more durable materials for reciprocating engine pistons and valves and for turbine heat exchangers, and cost reduction.

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Sponsor: DOE EERE Industrial Technologies Program

Silica buildup on piston formed during combustion from siloxanes in the landfill gas fuel

Honors, Awards, & Appointments

HONORS AND AWARDS

Claus Daniel, researcher in ORNL's Materials Science and Technology Division (MSTD), received an Early Career Award for Engineering Accomplishment at the 2009 UT-Battelle Awards Night for "catalyzing research in energy storage at ORNL through technical insights, strategic vision, and team building and for laying the groundwork for substantial funding increases by articulating a specialized and unique research and development program."

Claus Daniel

James Parks and ***William Partridge***, both of ORNL's Energy and Transportation Science Division, in collaboration with a researcher at DaVinci Emissions Services. Ltd., of San Antonio, Texas, have received an Excellence in Technology Transfer Award from the Southeast Region of the Federal Laboratory Consortium for Technology Transfer. They developed a laser-induced fluorescence fiber-optic measurement tool that quickly detects fuel dilution in engine oil. The thinning oil lowers lubricating ability, leading to increases in engine wear and oil consumption, as well as potential engine failure. Engineers will use the new tool to design durable engines that meet stringent fuel efficiency and emissions requirements.

James Parks

William Partridge

ORNL's research and operations programs in sustainability and energy efficiency were recently recognized by DOE's Office of Science. ORNL received "best in class" and "noteworthy practice" awards for its Efficient Energy Building and Sustainable Campus Initiative programs, respectively. ORNL used energy-efficiency technologies in a nearby Habitat for Humanity-built subdivision. These technologies were featured on the television show, "Extreme Makeover, Home Edition."

In April 2010 the Knoxville Chamber of Commerce presented the Schaad Companies with a Pinnacle Business Award in the "Innovator" category for its role in co-founding ZEBRAlliance and implementing its first project–4 highly energy-efficient research houses in the Crossroads at Wolf Creek subdivision in Oak Ridge. ZEBRAlliance was co-founded by Jennifer S. Banner of Schaad Companies and by ***Patrick Hughes*** of ORNL.

The Tennessee Valley Authority has bestowed its annual Climate Change Mitigation Environmental Excellence Award on TVA's Campbell Creek Research Team, for the unique test facility the team constructed that will enable TVA, **ORNL**, and the Electric Power Research Institute to evaluate the energy-saving effectiveness of different types of residential construction and efficiency technologies in a controlled environment. Three experimental homes were built in the Campbell Creek subdivision in Knoxville. Research results so far indicate that, compared with the standard house, the retrofitted home uses about 30% less energy and the highly energy-efficient house uses about 50% less energy. The data gathered from these houses will be used to evaluate residential building techniques, energy-efficiency technologies, smart-grid concepts, and consumers' energy-use behaviors.

Peter Blau

Peter Blau, an MSTD researcher, has written the novel *Solar Wind*, a techno-thriller published by Xlibris. The book can be ordered from Amazon.com or the publisher's website *http://www2.xlibris.com/bookstore/default.aspx.*

APPOINTMENTS

Ray Boeman

Ray Boeman has taken a temporary assignment as the point of contact for an ORNL-established satellite operation in Michigan that supports the state, the Michigan Economic Development Corporation, and a number of industries resident in the state. He continues to report to the associate laboratory director of ORNL's Energy and Engineering Sciences (EES) Directorate.

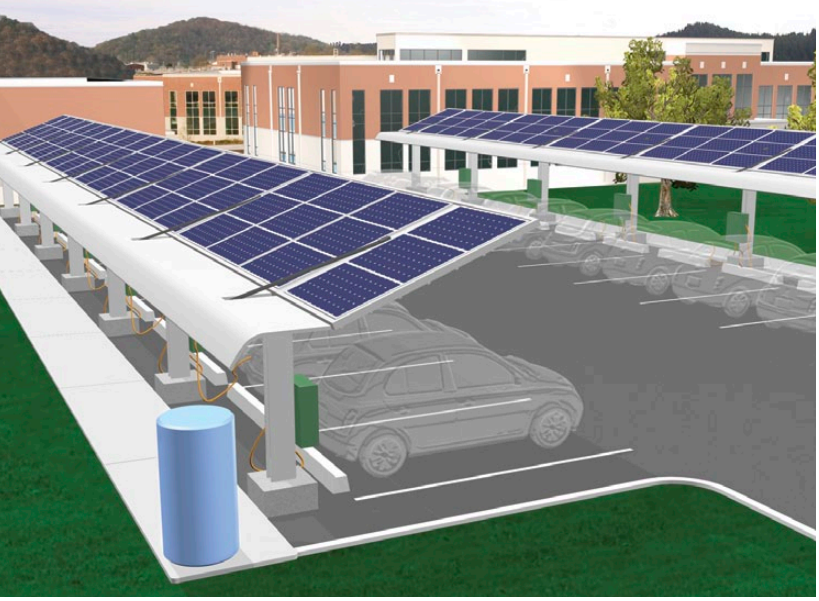
Ron Graves has been named program director for the Sustainable Transportation Program in the EES Directorate. This interim position encompasses EES initiatives for DOE EERE Vehicle Technologies, Biomass, and Fuel Cells Technologies programs, as well as the EES relationship with the Department of Transportation.

Ron Graves

Stan Hadley has been named ORNL relationship manager with DOE Wind Program team leaders. As a new manager in ORNL's Wind and Water Power Program led by Brennan Smith, Hadley and his team are focusing on the viability, applications, and acceptance of wind energy technology.

Stan Hadley

News Briefs



As part of ORNL's Sustainable Campus Initiative, employees who purchase or lease electric vehicles will have recharging available to them at a parking lot equipped with solar-assisted charging. Non-solar charging stations will also be available at various ORNL locations. In the solar-assisted scenario, each car is plugged in (yellow cord) to a charging station (green rectangular block). Some 2.5 kilowatts of solar capacity at each parking space will be part of an integrated charging system that includes the power grid and an external storage battery (blue cylinder).

Battery Charging Stations to Dot ORNL Campus

ORNL will install 25 solar-assisted charging stations to recharge the batteries of electric vehicles on the lab campus. The electric vehicles will be charged while parked under a roof covered with solar panels that convert the energy of sunlight to electricity. ORNL and partners will also install a number of non-solar charging stations. All these charging stations, which will be dispersed around the campus, will collect data on vehicle charging and the impact of charging on the electric grid.

In a recent survey approximately 130 ORNL staff expressed a strong interest in purchasing an electric vehicle, such as the new Nissan Leaf. The purchase or lease of the electric car will include installation of a charging station at the buyer's residence, other than substantial upgrades to the existing power supply. ORNL is participating with Nissan, the Tennessee Valley Authority, the Electric Power Research Institute, ECOtality North America (which builds charging stations), the state of Tennessee, and the Department of Energy in a joint effort to promote the use of electric vehicles and develop a better understanding of how this innovative mode of transportation will affect the electric grid.

ORNL Helps Company Develop Efficient, Power Producing Gas-fueled Engine

As oil and coal costs rise, many industries are examining ways to save energy and money in their daily operations. Through its Advanced Reciprocating Engine Systems (ARES) Program, DOE's Industrial Technologies Program seeks to help engine manufacturers take advantage of reduced natural gas prices. As an ARES program participant, Dresser Waukesha worked with ORNL to develop the Advanced Power Generation 1000 engine. This turbocharged, lean-burn unit has an efficiency of 42% and can reduce the cost of electricity by 10%.

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