Science & Technology HIGHLIGHTS

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What's in Store for Energy Storage Technology?

As the world's lightest metal, lithium is well positioned to meet demanding and growing energy storage needs for the future. Already commercialized for cell phones, laptops, and power tools, lithium ion and other innovative technologies are being developed and refined to meet energy storage needs for automobiles and the electric grid. To meet the desired extended driving range, lightweight, high-energy density, lithium ion batteries are attractive for plug-in hybrid and battery electric cars. Energy storage is a key element in achieving energy independence and reducing carbon emissions. However, "lithium ion and other advanced energy storage technologies must overcome significant performance, safety, and cost barriers to be successful in the marketplace," said Claus Daniel, technical lead for battery R&D at ORNL.

Claus Daniel examines advanced anode material powders under a protective atmosphere in a glove box. He leads R&D in degradation mechanisms of and materials processing for advanced electrochemical energy storage devices.

Traditionally, battery technology was driven by electrochemical advancements. To meet DOE and industry's performance, safety, lifetime, and cost goals, additional focus on advanced materials and process development, characterization of damage mechanisms, and performance modeling and simulation is needed to overcome barriers to widespread use of advanced batteries. Recognizing ORNL's core competencies in these disciplines, program directors from the Laboratory's basic science and applied programs formed an ad hoc steering committee in early 2007 to identify strategic opportunities to make significant contributions toward advancing energy storage technology. Through multi-year R&D funding commitments from the EERE's Vehicle Technologies (VTP) and Industrial Technologies (ITP) Programs and the Office of Electricity Delivery and Energy Reliability (OE), as well as from ORNL's internal investments and industry collaboration, energy storage R&D has grown by more than an order of magnitude to over $15 million per year in less than 2 years.

ORNL has established a growing transformational basic and applied research effort for next-generation electrochemical energy storage, complementing excellent work of other national laboratories and numerous companies. ORNL is well positioned to be a leader in a new focus in energy storage R&D on degradation mechanisms, new materials and systems, advanced materials processing, and modeling and simulation.

Building on long-time battery researcher Nancy Dudney's work and that of several other senior researchers with relevant expertise across the lab, ORNL has bolstered its research team dramatically over the past two years through the addition of extremely talented and multi-disciplinary researchers including ORNL-University of Tennessee Governor's Chair for Energy Storage Materials, Thomas Zawodzinski. ORNL also strengthened its industrial experience through the additions of Jagjit Nanda from Ford and George Andrews from General Motors. Electrochemistry expertise was added to the team by Xiao-Guang Sun from Arizona State University and David Wood from Los Alamos National Laboratory. Additionally, unique facilities are under development for in-situ characterization and advanced processing.

In 2009, ORNL established an internally funded cross-cutting initiative on energy storage to foster new concepts and conduct initial research to prepare for future external funding opportunities. Within this initiative, strategic investments have been made in metal-air, aluminum-ion, and all solid-state batteries; safety as a scientific issue; and systems level simulations. In July 2009, ORNL initiated a collaborative project with A123 Systems to develop and test improved, less-expensive, scalable, and environmentally benign processing techniques for producing materials for advanced lithium ion batteries. In early 2010, ORNL will announce collaborative projects with five battery companies that will be jointly funded by ITP, VTP, and the state of Michigan. About a dozen projects with industry and academia are under way through the High Temperature Materials Laboratory User Program headed by Edgar Lara-Curzio.

President Obama has set a goal of one million plug-in hybrid electric vehicles on American highways by 2015. Battery manufacturers, ORNL and other DOE national labs are working closely together to realize these ambitious goals.

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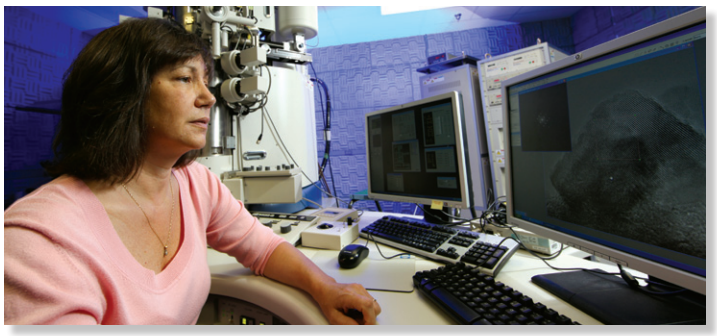
Sponsors: DOE Office of Energy Efficiency and Renewable Energy (EERE), Office of Electricity Delivery and Energy Reliability, and Office of Basic Energy Sciences

ORNL's Karren More led the design and construction of an in situ holder for studies of a working lithium ion battery inside an electron microscope. Interactions between novel electrode materials and liquid electrolytes during charge-discharge cycling will be observed.



ORNL's First Net-Zero-Energy Building

Why should a Department of Energy national laboratory reduce energy consumption and increase the use of renewable energy to meet its energy demands? The lab should implement recommendations and best practices that have been suggested by energy researchers, using less electricity from fossil fuel sources is good for the environment, and doing so will ultimately save money. But the most compelling reason is this: It's mandated by federal law!

The Energy Independence and Security Act of 2007 requires federal agencies "to reduce building energy intensity 30% by 2015 from the 2003 baseline." The act also requires "new Federal buildings and major renovations to reduce fossil-generated energy use 55% by 2010 and 100% by 2030." The Energy Policy Act of 2005 mandates that at least 5% of federal agencies' electricity will come from renewable sources during 2010–12 and at least 7.5% in 2013 and thereafter.

Early in FY 2010, ORNL self-declared Building 3156 to be a "net-zero-energy building" (NZEB)—a building with zero-net-energy consumption and zero carbon emissions each year partly because its needed electricity is produced on site using solar cells, a renewable energy source. Presuming DOE's due diligence bears out this declaration, Building 3156 will become the ninth commercial building nationwide to be recognized as an NZEB, the first retrofitted commercial building to achieve NZEB status, and the first DOE building of any kind to become an NZEB. Three other buildings on the west campus will be retrofitted to create NZEBs as part of ORNL's planned net-zero-energy, sustainable campus.

Building 3156 is an all-electric, two-story building with 23 offices that house 19 energy researchers and support personnel. The building and its equipment originally consumed about 100 MWh/year. Norman Durfee, aided by ORNL Energy Efficiency Manager Greg Palko and others, reduced the building's electricity consumption by 40%, from 100 to 60 MWh/year, through aggressive implementation of energy efficiency measures. The 60 MWh/year is provided by the solar photovoltaic power array located along Bethel Valley Road.

"The team used analysis to select the most cost-effective measures for reducing energy consumption," said Patrick Hughes, director of the Building Technologies Research and Integration Center.

Heating or cooling is provided for each office and the conference room of Building 3156 by highly efficient, air-to-air, through-the-wall, packaged terminal heat pumps (PTHPs), saving about 4 MWh/year. The new units replaced old, inefficient packaged terminal air conditioners.

Another measure is to control energy-consuming systems so they deliver lighting and comfortable temperatures only when people are present. By detecting absence of motion, occupancy sensors in each office turn off the lights and PTHPs automatically after employees leave. When a restroom is vacated, the exhaust fan turns off.

The use of occupancy sensors saves about 4 MWh/year, and the automatic shutdown of heating and cooling equipment in vacated spaces saves about 25 MWh/year. Strategically placed temperature and humidity sensors override occupancy control, preventing freezing and growth of mold and mildew.

Reducing the number of energy-hungry printers, photocopiers, and fax machines available to employees also saves energy. One of each machine is centrally located on each floor and networked to all office computers. Durfee and others worked with Sheila Causby of ORNL's Information Technology Services Division to reduce the power consumption of computers and other devices connected to the network. After each employee leaves for the day, power management software places each office computer into a standby mode. The users wake up their computers the next work day with one key stroke. Because the IT organization often requires installation of software updates on most networked computers at night, the Building 3156 computers are remotely powered up for the software updates, and the standby mode is resumed following installation. The power management software also monitors, measures, and manages the energy use of the computer and associated equipment.

In addition, smart power strips were installed in each office to eliminate unnecessary "miscellaneous energy loads" (MELs). This strategy assumes that, if a computer is not running, the office occupant has left, so other loads can be shed. The computer is plugged into the master outlet, which controls and automatically turns off power to the outlets where computer peripherals, battery chargers, and other MELs are plugged in. The reduction in plug loads by using fewer pieces of networked office equipment and smart power strips and the implementation of the IT changes saves 7 MWh/year. The total savings: 40 MWh/year.

Norm Durfee has been leading the effort to retrofit ORNL's Building 3156 (behind him) to create the laboratory's first net-zero-energy building.

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Sponsor: ORNL Sustainable Campus Initiative (http://sustainability-ornl.org)

White Roofs: Cool Solution for Slowing Global Warming

One "cool" solution to the problem of intensified global warming is the growing use of flat, "low-slope," white roofs to replace dark roofs on commercial buildings in cities. Light-colored "cool" roofs that reflect up to 80% of the light and heat in sunlight can reduce the demand for air conditioning by up to 15%, according to ORNL analyses. As a result, less generation of electricity by fossil-fueled power plants would be required, reducing emissions of carbon dioxide, which contribute to global warming.

During a climate change symposium on May 26, 2009, in London, England, Secretary of Energy and Nobel Prize–winning physicist Steven Chu advised Prince Charles and 19 other Nobel Laureates that roofs should be painted white to help avoid devastating climate change. As a result of Chu's widely publicized comments, in June 2009 the Department of Energy asked André Desjarlais, leader of the Building Envelopes Research group at ORNL, to produce a fact sheet on cool roofs. Desjarlais also learned that funding for his group will double.

A white roof saves energy by strongly reflecting sunlight (high solar reflectance) and efficiently emitting thermal radiation (thermal emittance). As a result, less air conditioning is needed.

Cool roofing is a hot topic now. In fact, cool roofing is the fastest growing sector of the building industry.

However, in the mid-1980s, when ORNL researchers in the Building Technologies Research and Integration Center first evaluated the impact on building energy use of light-colored roofing materials, their positive results were ignored by the building industry, probably because energy was cheap. Few people were concerned then that dark roofs reflect only 5 to 10% of sunlight, absorbing the rest as heat that warms building interiors.

In the early 1990s researchers at ORNL and Lawrence Berkeley National Laboratory published journal articles about the problem of the "urban heat island" caused by numerous city buildings with low-slope, dark roofs. Localized heating of city air significantly boosts demand for air conditioning and increases the number of unhealthy air days.

In the late 1990s the issue of global warming became more prominent. Desjarlais and his colleagues published journal articles on the ability of white roofs and other solar-reflective surfaces to slow global warming by reducing the demand for fossil power for air conditioning. Light-colored roofs also increase the comfort of residents who lack air conditioning.

The cool world movement has caused a significant shift in demand for roofing materials. Asphalt shingles have been the primary roofing material for buildings in the United States since the mid-19th century. But now, with growing demand for light-colored roofs to save energy, shingle makers face competition from polymer and metal roofs, even though they cost 20% to 100% more.

The roofing industry is gradually shifting from dark asphalt shingles to light polymer roofs at an annual rate of 2 to 3%. ORNL studies found that light-colored polymer roofs are durable and offer substantial energy savings for commercial buildings in a climate where air conditioning is needed about half the year.

Because homeowners consider dark roofs more aesthetically pleasing, the ORNL group has worked with pigment manufacturers to make dark-colored roofs more solar-reflective. "We found that the addition of certain pigments to black shingles makes them as high as 25% reflective," Desjarlais said. "So far our tests show that these modified shingles are durable and colorfast."

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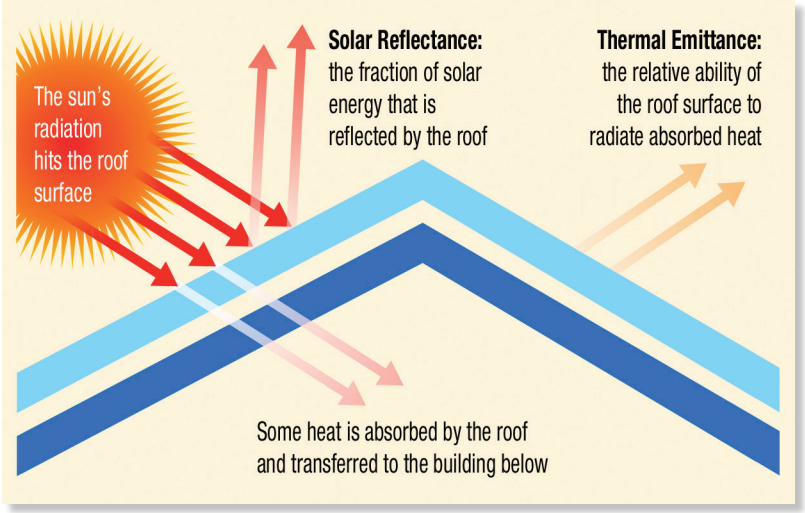
Sponsor: DOE EERE Building Technologies Program



R&D 100

Editor's note: In 2009 researchers at ORNL received eight R&D 100 awards, which are presented annually by* R&D Magazine *in recognition of the year's 100 most significant technological innovations. With 148 awards, ORNL has won more R&D 100 awards than any other Department of Energy national laboratory. In the following six pages are stories about ORNL's six energy-related awards won in 2009.

Next-Generation Superconductor May Be All-Ceramic Wire

Amit Goyal, one of the principal inventors of two ORNL award-winning, second-generation, high-temperature superconducting technologies that are being commercialized, has pioneered what could be the next generation of high-temperature superconductors—an all-ceramic wire. As a result, he won his third R&D 100 award in 2009. The other two awards he shared with ORNL teams in 1999 and in 2007.

With $100,000 in programmatic "seed" money, Goyal worked with researchers to prove his concept that an almost-round fiber of aluminum oxide (Al_2O_3), or a wire of sapphire, can be grown in long lengths from a starting crystal seed modified to have defined edges. A 10-m-long sapphire wire, about the thickness of an average human hair, was grown, and running along its length were two "pseudo-cubic" opposing flat surfaces on which a buffer layer and the superconductor yttrium-barium-copper oxide (YBCO) can be deposited.

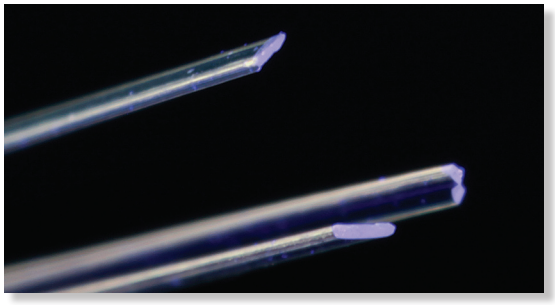
The title of the award-winning entry is "Superconducting Wires by Epitaxial Growth on Structural, Single-Crystal, Faceted Fibers." Several companies have expressed interest in the ORNL technology. Goyal received DOE funding to further develop the process.

"Our requirements were to grow a quasi-round wire as a single crystal from an edge-defined melt at long lengths, at high enough growth rates, and at a low enough cost to compete with conventionally used copper wire," Goyal said. Unlike superconductors, copper wire resists the flow of electricity and loses some energy as heat. Compared with copper cables of the same diameter, cables of oxide superconductors chilled by liquid nitrogen can carry five times the current and exhibit much lower alternating current (ac) losses in alternating magnetic fields.

The first technology that Goyal helped develop involves the production of tapes with a nickel substrate, a buffer layer, and YBCO. The problem with these tapes is that they exhibit high energy losses from the superconductor layer when conducting an alternating current or when subjected to an alternating magnetic field. To reduce the ac losses, each tape must be divided by a laser beam into filaments approximately 100 μm wide. Such a process is expensive and extremely difficult to scale up. Moreover, twisting and transposing the filaments from the flat tape is not feasible.

Round wires are more desirable because they require no further processing and can easily be twisted and coiled into bundles. Fewer steps reduce costs and increase productivity.

"This is the only known technology to fabricate a round, single-crystal, high-temperature superconducting wire needed for applications requiring low ac losses," Goyal noted. The applications include underground transmission cables, oil-free transformers, compact electric motors and generators, superconducting magnets for MRI medical imaging machines and accelerators for physics research, and high-speed levitated trains.



Sapphire wires showing quasi-round ends and two flat sides

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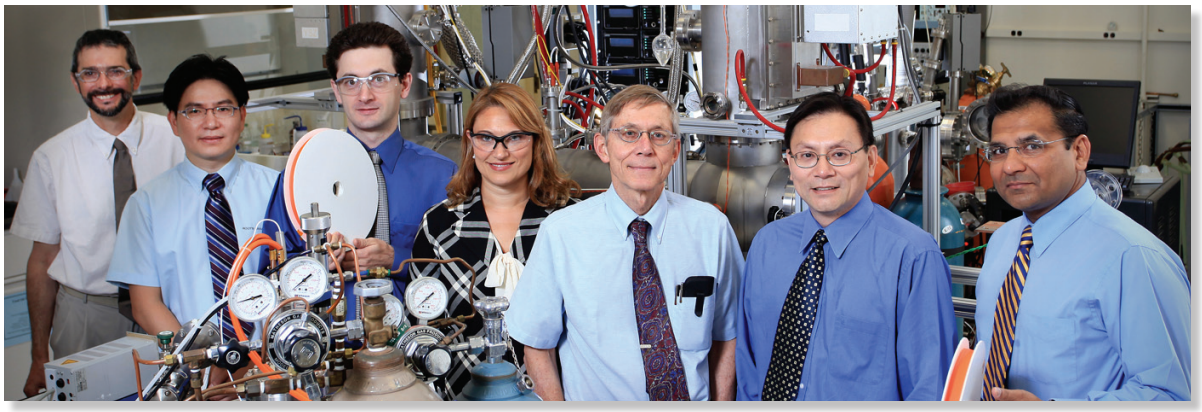
Sponsor: DOE Office of Electricity Delivery and Energy Reliability, Advanced Cables and Conductors



Winners of the R&D 100 Award for the high-temperature superconducting sapphire wire are, from left, Eliot Specht (developed way to use X-ray diffraction to characterize orientation of fibers and deposited layers), Sung-hun Wee (used pulsed laser ablation to grow layers), Yuri Zuev (measured tiny wire's superconducting properties), Claudia Cantoni (performed microscopy of completed samples), Jim Thompson (characterized samples using SQUID magnetometer), Dominic Lee (supported project programmatically, helped develop process), and Amit Goyal (principal investigator).

Winners

NovaCentrix, ORNL Are Partners in Rapid Thermal Processing

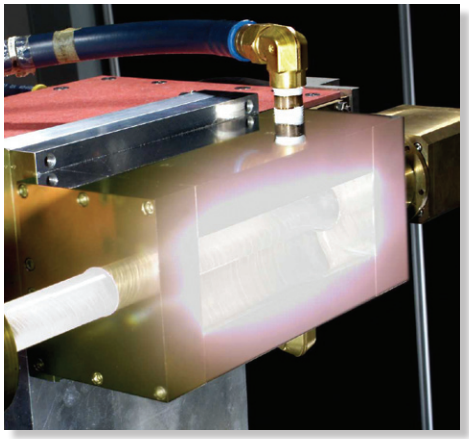
An engineer from a small solar company brings several samples of photovoltaic material to ORNL's Chad Duty. The engineer's company wants to know which rapid heating technology will best produce a thin film material with the desired optical and electrical properties. The processing information and ORNL's recommendations could help the company decide which heating tool to purchase as the small company moves toward large-scale manufacturing.

Duty, acting manager of the Solar Technologies Program, gives the engineer a tour of ORNL's Materials Processing Laboratory, where two plasma arc lamps (300 and 750 kW) are used for pulse thermal processing (PTP), a patented ORNL rapid heating technology. The lamp systems are manufactured by Vortek Industries, Ltd., a Canadian firm owned by Mattson Technology, Inc., of Fremont, California.

"Our two lamp systems provide more radiant light output than Neyland Stadium during a University of Tennessee Vols football game at night," said Duty. The plasma arc lamp can produce extremely high power densities over areas larger than one square foot. Instead of depending on an electrically heated resistive element to produce radiant energy, the arc lamp uses a controlled plasma.

The hot, stable plasma produces a broad radiant spectrum, ranging from ultraviolet to infrared. A reflector directs the radiant energy to the sample in a box below.

The plasma arc, which can be discharged in 1 millisecond, delivers power densities up to 20 kW/cm^2. Each pulse heats the surface of the sample at rates up to 600,000°C per second without significantly raising the temperature of underlying structures. This technology allows thermal processing of high-temperature materials on top of temperature-sensitive substrates, such as annealing a thin metal film on a plastic backing material. A sophisticated computer model is used to simulate the interaction of radiant light with a sample material and to predict the power level, range of wavelengths, and duty cycle needed to produce the desired result.



The plasma arc lamp used for pulse thermal processing

Such large-area processing speeds manufacturing by increasing the throughput. What's more, the one-dimensional thermal gradient produces uniform microstructures and less residual stress, improving structural integrity and providing more uniform electrical and optical properties. ORNL researchers led by Craig Blue, director of ORNL's Energy Materials Program, have demonstrated that the powerful flashes of radiant light from the plasma arc lamp can be used for various applications, ranging from direct manufacturing of thin sheets of metal from a powder bed to increasing the efficiency of solar cell materials.

PTP was licensed to NovaCentrix in 2008, the same year that the Austin, Texas, company sold its first PulseForge 3100 system. PulseForge uses a slightly different lamp technology for flash thermal annealing on a roll-to-roll platform, enabling inkjet printing of low-cost electronic circuit designs directly onto cheap paper and plastic. This technique dramatically lowers the cost of producing solar cells, displays, and radio-frequency identification tags and enables high-temperature processing of surface layers without affecting low-temperature flexible substrates. PulseForge can transform a printed ink circuit with high resistance to the flow of electricity to a highly conductive circuit on paper or plastic.

Recently, NovaCentrix sold the first of its latest rapid thermal processing tool—the PulseForge 3300—to ORNL, which serves as a beta test site for NovaCentrix to investigate new applications for the technology.

ORNL and NovaCentrix plan to combine and improve upon the best features of both PTP and PulseForge 3300 to create the next generation of powerful industrial heating tools. Rapid thermal processing represented by the partnership between NovaCentrix's PulseForge and ORNL's PTP tools received an R&D 100 award in 2009.

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Sponsors: DOE EERE Industrial Technologies Program; Department of Defense, DARPA Defense Sciences Office

The winning ORNL team for the R&D 100 award for pulse thermal processing are, from left, Ron Ott, Nancy Dudney, John Rivard, Art Clemons, Dave Harper, Chad Duty, Adrian Sabau, and Craig Blue.

Revolutionary Stainless Steels Could Save Energy

For 30 years alloy developers endeavored unsuccessfully to create a new class of aluminum-modified stainless steels that are both strong enough to retain their shape and more resistant to corrosion at high temperatures than are conventional heat-resistant stainless steels. Such low-cost steels could have a wide range of industrial uses. Now, a team led by Mike Brady in ORNL's Materials Science and Technology Division (MSTD) has invented a family of revolutionary stainless steel alloys that resist both corrosion (oxidation) and creep (sagging or deforming over time) at temperatures ranging from 600 to 900°C.

In the spring of 2006 under the Fossil Energy Advanced Research Materials Program, Brady and Yuki Yamamoto, then a postdoctoral researcher, discovered the long-sought metallurgical recipe for producing what they call a family of alumina-forming austenitic (AFA) stainless steels, an important breakthrough in energy-related metallurgy research. Unlike ordinary stainless steel, AFA steel in certain applications will enable energy production equipment to operate at higher temperatures, increasing their efficiency in consuming fossil fuels and lowering emissions of greenhouse gases, such as nitrous oxide and carbon dioxide.

"Use of advanced alloys such as AFA steel in coal-fired steam plants would result in higher operating temperatures and greater efficiencies," Brady said. "For example, studies indicate that raising the plant operation temperature from 538 to 650°C, along with higher steam pressures, would increase plant efficiency by eight percentage points—from, say, about 33 to 41%."

Besides Brady and Yamamoto, the inventors are Phil Maziasz, C.T. Liu, Bruce Pint, Mike Santella, and Zhao Ping Lu. The ORNL discovery was described in an article in the April 20, 2007, issue of the prestigious journal *Science*.

The Brady team then attracted companies to make and evaluate AFA stainless steel for recuperators in electricity-producing gas turbines. Recuperators, or heat exchangers, recover waste heat, enabling its use for improving turbine efficiency. Under cooperative research and development agreements, Carpenter Technologies is now making thin foils of AFA steel for evaluation in recuperators in low-emission, high-efficiency gas turbines manufactured by Solar Turbines and Capstone Turbine Corporation. These demonstration and commercialization efforts are funded by DOE EERE's Industrial Technologies Program.

As a result of the invention of the revolutionary steel and the subsequent commercialization efforts, the AFA steel received an R&D 100 Award in 2009. Sharing the award with Brady and the AFA inventing team are ORNL researchers David Stinton, Ian Wright, Jim Keiser, and Vinod Sikka, who also are helping commercialize the AFA steels.

"We are targeting companies that make tubing for chemical and petrochemical plants," Brady said. "These are two of the nation's most energy-intensive industries. AFA steel may also be attractive for use in solid-oxide fuel cells because it is less likely to cause chrome poisoning of the fuel-cell stack."

AFA stainless steels approach the creep resistance of and exhibit better high-temperature corrosion resistance than many high-performance nickel-base alloys, which are two to five times more expensive than AFA steels. The reasons: iron is cheaper than nickel, and lower levels of expensive alloying additions, such as cobalt, molybdenum, and tungsten, are needed for AFA steel.

Sample of ORNL's AFA stainless steel

AFA stainless steels are groundbreaking in that the corrosion resistance comes from an aluminum oxide (alumina) protective surface layer instead of the chromium oxide (chromia) surface layer that forms on conventional stainless steels. Alumina provides greater high-temperature corrosion resistance than chromia in many industrial-process and energy-production environments.

The researchers discovered that adding niobium enhances the formation of the alumina surface layer and that only a small amount of aluminum is needed.

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Sponsors: DOE Fossil Energy Advanced Research Materials Program, DOE EERE Industrial Technologies, Distributed Energy, and Commercialization and Deployment programs, and ORNL's Laboratory Directed Research and Development Program.

Members of the R&D 100 award-winning team that developed alumina-forming austenitic stainless steels are, from left, Bruce Pint, Dave Stinton, Ian Wright, Mike Brady, Vinod Sikka (retired), Phil Maziasz, Jim Keiser, Mike Santella, and Yuki Yamamoto.

A "Green" Temperature-Controlling Insulation

In some sports, a delay can bring a penalty. In residential and commercial buildings, however, delay of entry of afternoon heat will reduce peak-hour energy consumption for air conditioning, bringing lower energy bills for building owners while pleasing utility companies.

ORNL research shows that a new generation of enhanced insulations for walls, attics, and roofs can reap notable performance benefits. For several U.S. climates, space conditioning energy savings can reach 25%.

ORNL's Ján Kosny and David Yarbrough, in collaboration with industrial partners Microtek and Advanced Fiber Technology (AFT), have developed a new kind of "green," energy-saving insulation for buildings that is resistant to burning and not based on petroleum. The low-flammable insulation, which received an R&D 100 award in 2009, is made of sustainable materials from animal and plant sources.

About 20% by weight of the insulation consists of chemically treated fatty-acid esters present in waste fats from U.S. food and agricultural industries. These treated fatty esters serve as phase change materials (PCMs), helping reduce thermal stresses in buildings in about the same way that ice keeps drinks cool. In these new PCMs, drops of fatty acids are encapsulated in proprietary composite skins, forming small pellets between 5 and 50 μm across. These micro-pellets can be blended with cellulose, creating "dynamic insulation."

In these new materials microencapsulated PCM particles absorb heat from the sun, and at around 90°F, the esters melt into a liquid. At night, as the liquid cools, it turns into solid PCM, just in time to absorb and store the next day's heat.

"We call this insulating effect temperature control," said Kosny. "Our PCM in attic and wall insulation delays the entry of a summer heat wave into the house by six to eight hours. Some of this peak-hour heat will not enter the house until after midnight, when the interior space is already getting cool. In addition, during the night another portion of the heat energy is radiated back from the roof to the black night sky, cooling the attic."

Utility executives favor PCM insulation because it lowers the peak demand for electricity from utility power plants for space conditioning. As a result, utilities can better manage energy distribution, thus avoiding the expense of building new power plants or buying electricity from other utilities that would be needed to respond to peaks in demand.

The bulk of the new insulation consists of cellulose fibers from paper waste. The hair-like cellulose fibers provide good support for the microencapsulated PCM powders, to which flame retardant has been added. Cellulose is present in approximately 60% of the residential attics in the United States.

The ORNL PCM is stable and improves the efficiency of cellulose insulation blown into building envelopes. Compared with other PCMs, the ORNL insulation is not leaky or corrosive, and it is more heat resistant.

"Our PCM is the first of its kind to meet U.S. fire safety requirements," Kosny said. "What's more, it is an environmentally friendly alternative to conventional petroleum-based paraffins used as PCMs in Europe."

In 2008 Microtek made the fire-resistive PCM commercially available, and AFT started production of the first insulation product containing the PCM. AFT advertises the new product as a Dynamic PCM Cellulose Insulation on its website.

Microtek produces and sells fire-resistive PCM microcapsules.

The fiberglass industry has more than 80% of the market share for the residential sector, so Kosny and his colleagues have also integrated the fire-resistive PCMs with fiberglass in the laboratory. The PCM-fiberglass insulation has been blown into prototype walls and an experimental attic of ORNL's Roof Research Facility for field testing sponsored by a leading fiberglass manufacturer. Over 18 months of field testing demonstrated dynamic performance as good as that of the cellulose-PCM blends. With adequate funding, Kosny's team aims to arrive at energy-efficient solutions for new and existing buildings with minimal delay.

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Sponsor: DOE EERE Building Technologies Program

Members of the R&D 100 award-winning team that developed the fire-resistive insulation with phase change material are, from left, David Yarbrough (ORNL), Ján Kosny (ORNL), Douglas Leuthold (AFT), and Tim Riazi (Microtek).

Estimating Life of Power-Line Connectors

"Power Surge Blacks Out Northeast, Hitting Cities in 8 States and Canada; Midday Shutdowns Disrupt Millions" shouted the three-line headline at the top of the front page of the August 15, 2003, edition of the *New York Times*. The blackout shut down the New York City subway and building elevators. Thousands walked home from work that day.

The August 14 blackout was triggered when a sagging power line came in contact with a tree. "Because of rising demand for air conditioning on a hot day, more current was put across this line, causing it to heat up," said Edgar Lara-Curzio, director of DOE's High Temperature Materials Laboratory and leader of the Mechanical Properties and Mechanics Group at ORNL. "The hotter a line gets, the more it expands. An elongated line will sag and, if it contacts a tree, a short circuit could occur."

The blackout, which denied power to many manufacturers for at least a day, cost the U.S. economy an estimated $6 billion. It was a wakeup call for the electric utility industry, DOE, and the Department of Homeland Security.

"Increases in power demand have forced existing overhead power transmission cables in the United States to operate at temperatures higher than these aging power lines were designed for," Lara-Curzio said. "The biggest problem is the weakest link in the power-line system chain—the splice connectors that join the power lines. The accelerated aging and degradation of splice connectors as a result of high-temperature operation increase the chances for power outages, including large-scale blackouts that could threaten homeland security."

Lara-Curzio proposed to the Electric Power Research Institute (EPRI) that a mathematical model be developed to simulate the performance of a conductor-connector system under various operating conditions and to predict its effective service life for each scenario. The software package would integrate the results of analytical and experimental protocols with information from a database of material properties and on the service history of the conductor. The project was approved and funded, thanks to the Tennessee Valley Authority's (TVA's) Joe Graziano and EPRI's John Chan, who both recognized the importance of the proposed model for electric utilities.

Tom King, manager of ORNL's Energy Efficiency and Electricity Technologies Program, helped secure DOE funds for the project. Another collaborator was Tip Goodwin III of PBS&J, Inc. He provided measurements of temperature changes in splice connectors and connector failure data to help the model more accurately predict when a connector will fail.

The result of the project led by principal investigator John Jy-An Wang in Lara-Curzio's group is the "Methodology for Estimating the Life of Power Line Conductor-Connector Systems Operating at High Temperatures" (MELCOT). MELCOT and the people named above received an R&D 100 Award in 2009. MELCOT is commercially available and used to guide the design of more durable power-line connectors.

Using daily records of a given region's temperature and electric current changes as well as known properties of the conductor and connector materials, Wang's model can simulate the behavior of the connector material over time under different temperature ranges and stresses related to frequent increases and decreases in electric current to meet ever-changing demands. The model predicts when a connector will likely fail, allowing utility personnel time to replace the aging connector to avoid disruption of power delivery.

High temperatures widen gaps between the connector and power-line conductor, increasing resistance and heat losses.

A typical power line consists of a steel-wire core surrounded by aluminum wires, which conduct electricity. The steel core confers strength and stiffness to the transmission cable. The connector is a tube through which two power-line ends are inserted until they meet. Then a die powered by a hydraulic press squeezes the connector and power-line ends together. The model predicts the residual stresses induced in the connector from the die's clamping force. Using neutron scattering at ORNL's High Flux Isotope Reactor, the team worked with Cam Hubbard and Ke An to determine the stresses in a connector after being squeezed. The experimental results confirmed MELCOT predictions. This approach is now being considered for use with advanced conductors.

Someday MELCOT might help prevent America's power lines from making negative headlines.

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Sponsors: DOE Office of Electricity Delivery and Energy Reliability, Advanced Cables and Conductors; EPRI, TVA

Members of the R&D 100 award-winning team that developed MELCOT are, from left, Tom King, (ORNL), Joe Graziano (TVA), Edgar Lara-Curzio, and John Wang (ORNL).

Thermomagnetic Process Attracts Industrial Partners

Considerable energy from the combustion of natural gas and oil is required by American industry to heat-treat metal components to give them the desired properties. Often electricity from a coal-fired power plant is needed for a refrigeration unit to chill the material to eliminate an undesirable effect of its production, such as residual stresses that can lead to cracking. Such stresses result from thermal strains as the material's crystal structures expand and contract differently during repeated heating and cooling.

At ORNL, researchers led by Gerard Ludtka have introduced a low-temperature superconducting magnet into the industrial mix, making them a magnet for industry. They have shown that a state-of-the-art superconducting magnet combined with induction heating can reduce the need or time required for industrial heating and cooling of materials, saving energy. This technology, in which a magnetic field permeates a material instantly, unlike any heating or cooling process, can prevent the formation of residual stresses, enabling the material to have a longer and more reliable service life.

Ludtka calls thermomagnetic processing (TMP) "a transformational, energy-efficient, and energy-savings materials processing technology that adds an entirely new dimension to the industrial processing of materials and components." This technology received an R&D 100 award in 2009 for ORNL and its partners.

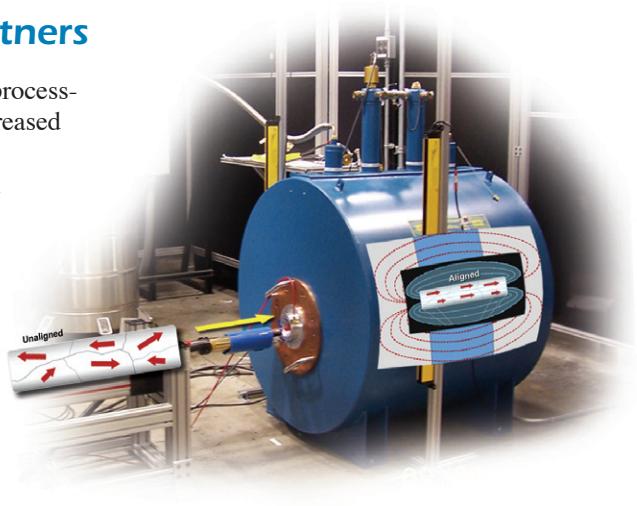
Ludtka's group has attracted industrial partners largely because TMP consumes significantly less energy than conventional heat-treating through the use of new energy-efficient, cost-effective superconducting magnets that generate increasingly stronger magnetic fields with low energy requirements.

The new process can save time as well as energy. "In the foundry, it takes two hours to temper a martensite steel to get the right crystal structure," Ludtka said. "We can do it with our magnet and induction heating system in ten minutes."

TMP enables the creation of entirely new microstructures unachievable by any other processing technology. "Our process increased by 30% the solubility of nickel in iron, producing a new iron-nickel alloy," Ludtka said. "We expect to demonstrate how to make the next generation of materials, such as precipitation-hardened steels and magnesium alloys."

The auto industry is looking for structural materials that are lighter than steel but just as strong for making vehicles that will consume less fuel per mile yet protect passengers during traffic collisions. Candidate materials include precipitation-hardened magnesium alloys. "Using our magnetic field, we have increased by 15% the strength of these magnesium alloys," said Ludtka. This means that thinner sheets of lightweight magnesium alloy can be used to make a safe vehicle, enabling the design of a lighter-weight, less expensive car with higher fuel efficiency.

TMP can enhance the performance of materials by dramatically improving their strength, resistance to fracture and wear, and lifetime; soften some materials, making them easier to shape into desired components; and increase magnetic permeability, enabling higher efficiencies in the operation of electric motors.



In thermomagnetic processing, the superconducting magnet's field aligns atoms in the sample.

ORNL's industrial partners included in the R&D 100 award are Eaton Corporation, which manufactures motors; American Magnetics Inc. (AMI) of Oak Ridge, which builds superconducting magnets for ORNL; and Ajax TOCCO Magnethermic Corporation, which incorporated induction heating in the TMP setup at ORNL.

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Sponsors: ORNL Laboratory Directed Research and Development Program, DOE EERE Industrial Technologies and Vehicle Technologies Programs, various companies

R&D 100 award winners for thermomagnetic processing (carried out by device in background) are, from left in front row, Vinod Sikka (ORNL retiree), Roger Kisner (ORNL), Gerry Ludtka (ORNL), Gail Ludtka (ORNL), Aashish Chourey (AMI), Ed Hatfield (ORNL retiree), and Craig Blue. Back row, from left, are Aquil Ahmad (Eaton), George Pfaffmann (Ajax TOCCO), Alex Bogicevic (Eaton), John Kovacich (Eaton), John Wilgen (ORNL), Greg Laughon (AMI), and Ronny Efferson (AMI).

Honors and Awards

Edgar Lara-Curzio

Craig Blue

Amit Goyal

Edgar Lara-Curzio, director of ORNL's High Temperature Materials Laboratory, received the 2009 Arthur Frederick Greaves-Walker Award from the American Ceramic Society and the National Institute of Ceramic Engineers, in recognition of his "outstanding service to the ceramic engineering profession."

Craig Blue, director of ORNL's Energy Materials Program, has been elected a fellow of ASM International, for his contributions to materials science and engineering.

Amit Goyal, an ORNL corporate fellow and eminent researcher in superconducting materials in ORNL's Materials Science and Technology Division (MSTD), has been elected a fellow of the prestigious World Technology Network for his innovative research in materials science; named a finalist for the World Technology Network's materials award; and given the "Distinguished Alumnus Award" for 2009 from his alma mater, the Indian Institute of Technology, at Kharagpur, India. Goyal ranks number one worldwide in the total number of citations and number four worldwide in the total number of papers published during the past decade (1999–2009). Other ORNL researchers who made the list include Elbio Dagotto, Dave Christen, M. Paranthaman, Dominic Lee, Ron Feenstra, Eliot Specht, Claudia Cantoni, Don Kroeger, Fred List, and the late Patrick Martin.

Johney Green

Sharon Robinson

Jun Qu

Johney Green, director of ORNL's Energy and Transportation Science Division (ETSD), will receive a "special recognition" award at the 2010 Black Engineer of the Year STEM Conference. The Council of Engineering Deans of the Historically Black Colleges and Universities, *U.S. Black Engineer* and *Information Technology* magazines, and Lockheed Martin Corporation will present the award, which recognizes Green "for distinguished achievement outside of his professional discipline, high merit, broad impact on people in other disciplines, and value to society as a whole."

Sharon Robinson, former manager in ORNL's EERE program, has been elected a fellow of the American Institute of Chemical Engineers (AIChE) "for her distinctive professional accomplishments and contributions in chemical engineering." AIChE also selected her as the 2009 winner of the prestigious Robert E. Wilson Award for her achievements in nuclear engineering.

Jun Qu, of MSTD, is the 2009 winner of the Outstanding Young Manufacturing Engineer Award from the Society of Manufacturing Engineers.

Leon Tolbert

Leon Tolbert, of ETSD, received a 2009 IEEE Power Electronics Society Transaction Prize Paper Award for coauthoring "Multilevel DC-DC Power Conversion System with Multiple DC Sources."

CF8C-Plus stainless steel developed with Caterpillar, Inc., at ORNL by **Phil Maziasz** and others continues to garner awards. ORNL and Caterpillar received the Federal Laboratory Consortium's 2009 national award for excellence in technology transfer. CF8C-Plus was developed for use in the regeneration systems of diesel engines in heavy equipment produced by Caterpillar. More than 450 tons of CF8C-Plus steel have been cast, producing tens of thousands of parts that have yet to fail. The steel, which received an R&D 100 award in 2003 and the 2008 Project of the Year award from FLC's Southeast Region, is critical to the

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OAK RIDGE NATIONAL LABORATORY
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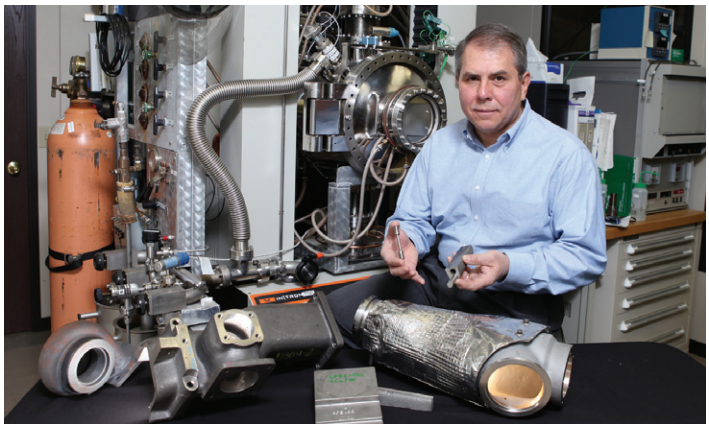
Phil Maziasz

periodic cleaning of ceramic filters that trap carbon-containing particulates from diesel engine exhaust gas. The burner chamber ahead of the filters is made of CF8C-Plus steel. The intense heat from the chamber chemically breaks down the particulates. The remaining carbon in the filter is burned away, regenerating the filter.



Governor's Chairs

Yilu Liu

Yilu Liu, an expert in the technologies used to monitor power grids who is researching ways to create the next-generation "smart grid," has been named the fourth University of Tennessee–Oak Ridge National Laboratory Governor's Chair. Liu was the director of the Center for Power Engineering at the Virginia Institute of Technology. She will hold appointments in ORNL's Energy and Transportation Science Division and the Department of Electrical Engineering and Computer Science in UT Knoxville's College of Engineering.

Thomas Zawodzinski

Thomas Zawodzinski, an innovator in fuel cell development and related energy storage science and technology, has been named the fifth UT-ORNL Governor's Chair. He is serving as the Governor's Chair for electrical energy storage in the Chemical and Biomolecular Engineering Department at UT Knoxville and in the Physical Chemistry of Materials Group in ORNL's Materials Science and Technology Division. Previously he was the F. Alex Nason professor of engineering, the Ohio eminent scholar for fuel cells, and the director of the Case Advanced Power Institute at Case Western Reserve University.

The Governor's Chair program, funded by the state of Tennessee and ORNL, attracts top scientists to broaden and enhance the unique research partnership that exists between the state's flagship university and the nation's largest multiprogram laboratory.

Wide Single Tires Reduce Truck Fuel Costs

Wide single tires on heavy trucks enable the vehicles to use 6% to 10% less diesel fuel than the same tractor-trailer trucks traveling an equal distance under similar conditions on standard pairs of narrower tires. For comparable trips by trucks with single tires versus those with dual tires, the reductions in fuel costs and requirements for trucks with wide single tires are attributed to these factors: wide single tires lower the tractor-trailer weight by about 600 pounds, the proprietary tread design and tire formulation are intended to elicit improved fuel performance, and the rolling resistance on roads is less than that of standard dual tires. In addition, wide single tires could be safer than standard dual tires because they have the potential for enhancing roll stability.

These findings were reported in March 2009, when ORNL researchers at the National Transportation Research Center released copies of a technical memorandum approved by their sponsor, the Department of Energy's Vehicle Technologies Program. The authors of the report are Gary Capps, Oscar Franzese, Bill Knee, Mary Beth Lascurain, and Pedro Otaduy. Capps led the testing, Lascurain prepared the technical memorandum,

continued on next page

Sue Nelson (Michelin), with a new generation single wide-based tire on one of the Schrader instrumented tractor-trailers

and Knee led the program. Knee is director of heavy truck safety research in ORNL's Energy and Transportation Science Division.

According to the report, six instrumented tractors and 10 trailers hauled freight more than 700,000 real-world miles on regular runs over 12 months. On-board instruments recorded 300 pieces of information per second from truck operations. On-board data acquisition systems measured 60 performance parameters, such as instantaneous fuel consumption, payload weight, engine speed, acceleration, gear used, location, time of day, wind speed and direction, precipitation, and road grade. Each truck had a weather station; global positioning system; and commercially available, real-time, self-weighing system. The data are being used for computer modeling that will aid the design of the truck of the future. The goal of both the trucking industry and transportation researchers is to develop more-energy-efficient and safer vehicles.

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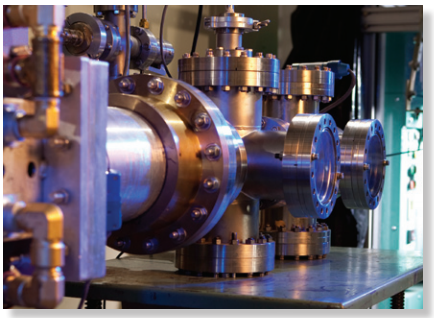
Sponsor: DOE EERE Vehicle Technologies Program

ORNL Receives $55 Million for DOE Energy Projects

ORNL will receive $54.9 million from the Department of Energy to help DOE "tackle the great challenges of our day, including energy and climate," said Deputy Secretary Daniel Poneman. ORNL will get $34.7 million to construct the Carbon Fiber Technology Center. The Center's users will investigate novel carbon fiber manufacturing processes and alternative feedstocks to lower the cost from the current $10–$20 per pound to under $5 per pound.

Carbon fiber is a lightweight, high-strength material that has the potential to revolutionize the automobile and wind industries. Low-cost carbon fiber is critical to reducing the weight of vehicles, thereby raising their fuel efficiency while maintaining the strength and safety present in steel bodies of cars.



Apparatus used in the experimental production of carbon fibers

ORNL will also receive $20.2 million from DOE to develop an Integrated Net-Zero-Energy Buildings Research Laboratory that includes a commercial building field research platform.

Net-zero-energy buildings (NZEBs), which generate as much energy as they use annually through high-efficiency appliances, enhanced insulation, and on-site renewable energy generation, are essential for significantly reducing energy use and carbon emissions. New laboratory facilities will develop the design approaches and technologies that will enable construction and operation of NZEBs at low incremental cost.

Climate simulator for testing attic and wall insulation at different temperatures

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