OAK RIDGE NATIONAL LABORATORY

Vol. 38 • No. 1 • 2005
www.ornl.gov/ORNLReview

REVIEW

• MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY •

Addressing the *World's Energy Challenges*

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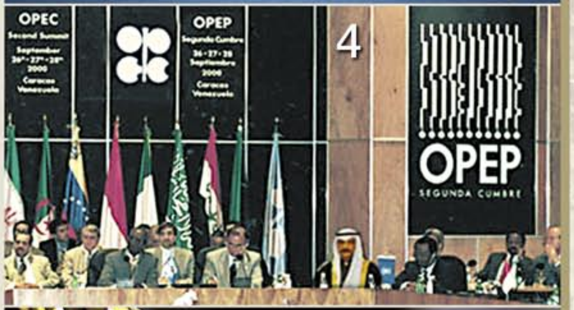
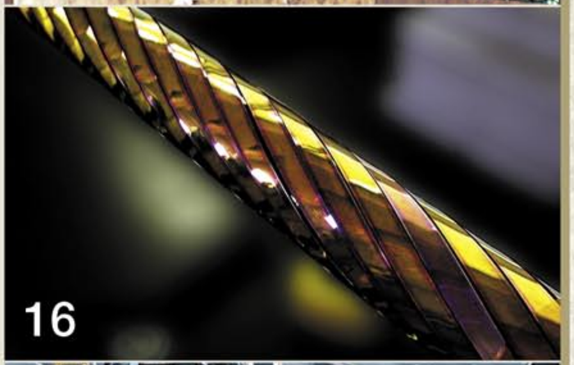
Features





COVER: Calcutta, India

An Important Part of The Solution

Oak Ridge National Laboratory is the nation's leading energy research and development laboratory. This simple statement encompasses a wide range of activities and brings to mind images of coal-fired power plants, nuclear reactors, fusion devices, and overhead electricity transmission lines. But as we envision the nation's energy future here at ORNL, we focus on more than large-scale energy generation and transmission concerns for the Department of Energy. We also address the many issues that surround how energy is distributed and ultimately consumed, as well as how to encourage a more efficient use of energy.

The events of recent years have taught us the importance of energy to the stability of the world's economic and political systems. The worldwide recession caused by the first oil price shock of 1973 led to an explosion of new technologies and fostered new policies that encouraged more efficient energy use. Since that time, the United States has reduced the economy's energy intensity by 1 to 2% per year, thereby avoiding imports of billions of barrels of oil and the release of millions of metric tons of carbon and other health-threatening pollutants into the atmosphere. While today there is a lively debate on the causes and consequences of global climate change, the reality of climate change is increasingly accepted. This realization, combined with the recognition that the world needs ever-increasing supplies of energy to sustain the industrial economies of the developed world, as well as the rapidly growing economies of countries such as China and India, has led to increased attention not only to the problems of energy supply and demand but also to the need for more energy R&D worldwide.

Energy efficiency must be part of any solution to the world's energy challenge. At ORNL, our energy efficiency R&D draws upon a science base, with a focus on translating research results into technology solutions that enable energy resources to be used more productively. Our R&D is characterized by a close working relationship with industry, states, and the Tennessee Valley Authority because, ultimately, if the technologies are not economically viable, they will not be accepted in the marketplace. ORNL researchers have been exploring technologies that would significantly reduce the use of petroleum-based fuels. Examples of these technologies include lightweight materials for transportation vehicles, production and storage of hydrogen, and power electronics for hybrid engines. We also have generated an equally wide range of innovative products, such as hybrid solar lighting, highly efficient refrigerators, low-energy-use houses, and superconducting wire, in addition to micro-grid systems. Oak Ridge's work for DOE's Office of Energy Efficiency and Renewable Energy and the Office of Electric Transmission and Distribution has led to no less than 46 of the R&D 100 awards given by *R&D Magazine* since 1963 to recognize each year's top 100 innovations. This issue of the *ORNL Review* provides a broad overview of ORNL's contribution to improving energy efficiency, reducing U.S. dependence on foreign energy sources, and developing long-term solutions to the world's energy needs.

David J. Hill
ORNL Associate Laboratory Director
Energy and Engineering Sciences

ENERGY EFFICIENCY: Stretching America's Resources

ORNL continues a long tradition of contributing energy-efficient technologies to the buildings, industrial, transportation, and power sectors.

The United States and the world face enormous energy challenges. Petroleum prices are at record highs with no end in sight. The emergence of China and India as major contributors to global demand brings new urgency to political and economic concerns about oil dependence. Simultaneously, sustained price increases and extreme volatility in natural gas markets are prompting renewed anxieties about this environmentally valuable fuel. In the wake of the largest cascading power outage in North America's history, the U.S. has not developed sufficient improvements to an outdated electric grid that is essential to nearly every facet of modern life. Each of these issues lies in the context of deteriorating air quality that continues to impair human health and adds to growing concerns that increased fossil fuel use may be contributing to global climate change.

Using energy more efficiently can help address each of these challenges. The offer of a "no regrets" approach makes energy efficiency particularly valuable as a "front-line" strategy. Investments in energy efficiency hold the promise of saving consumers money while reducing pollution and greenhouse gas emissions and stretching our limited energy resources.

High-visibility conditions in the Smoky Mountains—100 miles (top) and low-visibility—20 miles (bottom)

Energy efficiency has already played a significant role. Before the 1970s, America's energy consumption grew in parallel with the nation's gross domestic product (GDP). Had that trend continued, current U.S. energy demand would be roughly doubled. Reductions in energy intensity (E/GDP) have resulted from a combination of energy efficiency investments, structural shifts away from energy-intensive manufacturing toward a service and information-based economy, and the pressures brought by historic increases in the cost of energy.

Despite three decades of "clean air" legislation in the United States, air pollution continues to be a serious environmental problem. Americans are experiencing a rise in respiratory illnesses. Visibility continues to degrade at least in part as a result of power plant and vehicle emissions. The Great Smoky Mountains National Park, ORNL's neighbor to the east, is a case in point. Ozone alerts dissuade visitors from hiking and prevent rangers from working several weeks each year. Once breathtaking, visibility in the Smoky Mountains now rarely achieves its "natural" limit of 93 miles. Today, average annual visibility has decreased in winter to an average of 25 miles and in summer to an average of 12 miles.

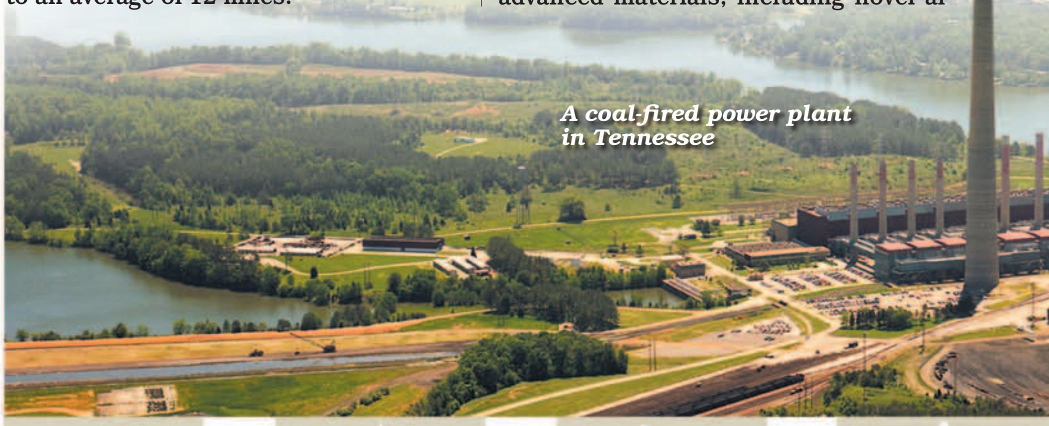
Attacking the Problem

ORNL is contributing a variety of energy-efficient technologies for future generations. Every kilowatt saved through energy conservation, i.e., "negawatt," displaces the same amount of energy generation, thus reducing air emissions from power plants.

The buildings sector uses 70% of the electricity consumed in America, meaning that energy-saving construction and building equipment technologies can dramatically impact air quality. ORNL's energy-saving technologies for buildings include advances in water heating, heat pumps, air-conditioning, and building materials.

Over 25 years, due in part to ORNL research, the amount of electricity consumed by American refrigerators has dropped by more than two-thirds, saving $9 billion. A new refrigerator developed jointly by the Laboratory and industry uses 60% less electricity than comparable conventional units. ORNL advances in supermarket refrigeration, including sophisticated approaches to recovering waste heat, are also cutting energy costs. The Laboratory has developed "calculators" for evaluating the energy performance of roof and wall systems. Its *Insulation Fact Sheet*, the second most requested DOE publication, is used on virtually every insulation package sold in the United States.

For industry, ORNL has developed advanced materials, including novel al-



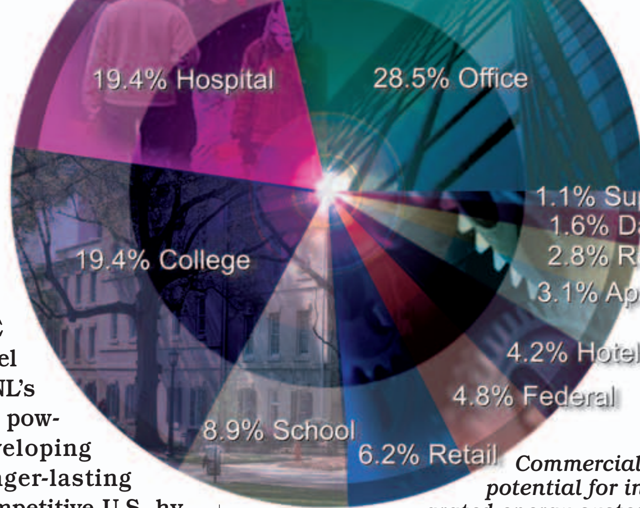
A coal-fired power plant in Tennessee

loys and nano-engineered, high-performance steels. For DOE's Best Practices program, ORNL helps minimize waste streams while upgrading energy efficiency, particularly in heavy industry. New metal-processing technologies pioneered at ORNL have a high potential for lowering energy use even as they reduce waste and enhance product performance.

One success story involves nickel aluminide alloys, which are extraordinarily strong, hard, and heat-resistant materials now widely used in fixtures for high-temperature manufacturing. These ORNL-developed alloys can cut energy use 10 to 35% by making it feasible to operate furnaces at higher temperatures with fewer shutdowns and greater throughput. In 2003, Delphi Automotive Systems initiated the use of nickel aluminide trays for steel-carburizing, heat-treating furnaces and announced plans to use them in worldwide operations. Bethlehem Steel, now ISG, installed 100 rolls made of nickel aluminide alloys in its steel mills. Use of the new rolls has resulted in an increase in up-time by 30%, a higher yield of steel with improved quality, lowered operating and maintenance costs, and a 35% reduction in energy use.

For the transportation sector, ORNL researchers helped develop lightweight composites present in production vehicle parts such as truck beds, Aston-Martin body panels, and Delphi Class 8 tie rods. Each 10% reduction in weight enables a 5 to 6% improvement in fuel economy.

Every advance in fuel efficiency and emissions control for vehicles translates into tailpipe emissions avoided. ORNL's extensive research and development portfolio in advanced technologies will improve the efficiency of internal combustion engines (ICEs) for both transportation and power applications. At the National Transportation Research Center, ORNL researchers are developing technologies to allow more effective control of ICE emissions without a fuel economy penalty. ORNL's research on advanced power electronics is developing smaller, cheaper, longer-lasting inverters to enable competitive U.S. hybrid vehicles. For the long term, ORNL is conducting research on gas separation, advanced sensors, and materials to help enable a hydrogen economy.



Commercial market potential for integrated energy systems that use waste heat productively, raising fuel-use efficiency from 32% to 70%

Using Waste Heat Well

In the power sector, distributed energy technologies can more than double today's average electric system efficiency through the use of integrated cooling, heating, and power (CHP) systems that capture and use waste heat productively instead of venting it to the atmosphere. The improvement in fuel efficiency means corresponding improvements in air quality. Working with industrial partners, ORNL project managers have helped demonstrate the practicality of using industrial gas turbines, microturbines, and reciprocating engines in CHP systems at a number of different sites.

DOE initiated the Advanced Turbine Systems program because projections indicated that natural gas turbines, which generate from 3 to 30 megawatts, would make up 80%+ of new capacity during the 1990s. To increase efficiencies, the gas turbines had to operate at higher temperatures and pressures than ever before.

ORNL researchers identified ceramic composite materials for combustor liners in these turbines, enabling them to operate at higher temperatures without violating environmental regulations. Coatings were added to protect the materials from degrading when exposed to corrosive reactions. The result was Solar Turbines' Mercury 50, a new class of industrial gas turbine that incorporates advances stemming from ORNL research, including an improved stainless steel alloy. By applying this alloy to recuperators, heat can be recovered from the exhaust to pre-heat inlet air, raising the gas turbine's efficiency to 40%.

More recently, ORNL has developed a facility to evaluate metals and ceramics that are potential candidates for microturbine components in the quest to raise microturbine efficiency from 27% to 40%. ORNL researchers are also applying control techniques to reduce combustion variability in reciprocating engines.

Recognizing that transmission is a critical part of the energy equation, ORNL also is a leader in developing superconducting technologies that could dramatically improve the efficiency and reliability of the U.S. electric grid. The use of new superconducting cables to reduce the substantial losses that occur as electricity is transmitted from generator to end user will proportionately reduce the need for power generation and will help stabilize the electric grid.

As the demand for energy services grows, technologies developed at ORNL and elsewhere that generate "negawatts" will be increasingly important, helping to ensure that America's economic vitality is not sustained at the expense of our health and environmental quality.—*Marilyn Brown, director of the Energy Efficiency and Renewable Energy Program at ORNL.* Ⓡ

Providing International Solutions

American security will require addressing the energy challenges of other nations as well as our own.

As U.S. researchers focus on domestic energy issues, they could easily miss the century's dominant energy challenge: to increase energy supplies for the world's growing population without contributing further to environmental degradation. Accomplishing this monumental task would represent the most fundamental change in the world's energy production since the Industrial Revolution.

By 2100, world energy consumption is projected to have increased by nearly four-fold, with most of the growth occurring in developing countries such as China and India. Analyses conducted for the United Nations Conference on Environment and Development in 1992 estimated that total global energy services need to be increased by 7 or 8 times to reduce gaps between the world's rich and poor nations.

To reach the formidable goal of significantly expanding global supplies of energy services without a corresponding increased threat to the world environment, tomorrow's energy systems will have to be dramatically different from those employed today. The International Energy Agency, for example, is studying technologies and policies that within 50 years might provide global energy systems with net emissions of carbon dioxide near zero. The study suggests the ambitious goal is possible only by accelerating research and development on carbon-emission-avoiding resource technology combinations, pursuing multiple technology pathways rather than depending on any single solution, and paying particular attention to expediting the difficult transition from one energy system to another.

Although the challenges are daunting, for industrialized nations the most cost-effective solutions currently focus on energy efficiency improvements. In the early 1990s, the "grand old man" of China's coal industry observed: "We can do far more to reduce our need for coal by improving energy system efficiency than by switching to other energy sources." In most countries, opportunities abound to improve the efficiency of buildings, building equipment, industry, and electricity systems. In industrialized nations, the transportation sector is an opportunity as well. Because the economies in some of these countries are growing rapidly, viable environmental progress could be made

Energy Prophets

U.S. Oil Dependence

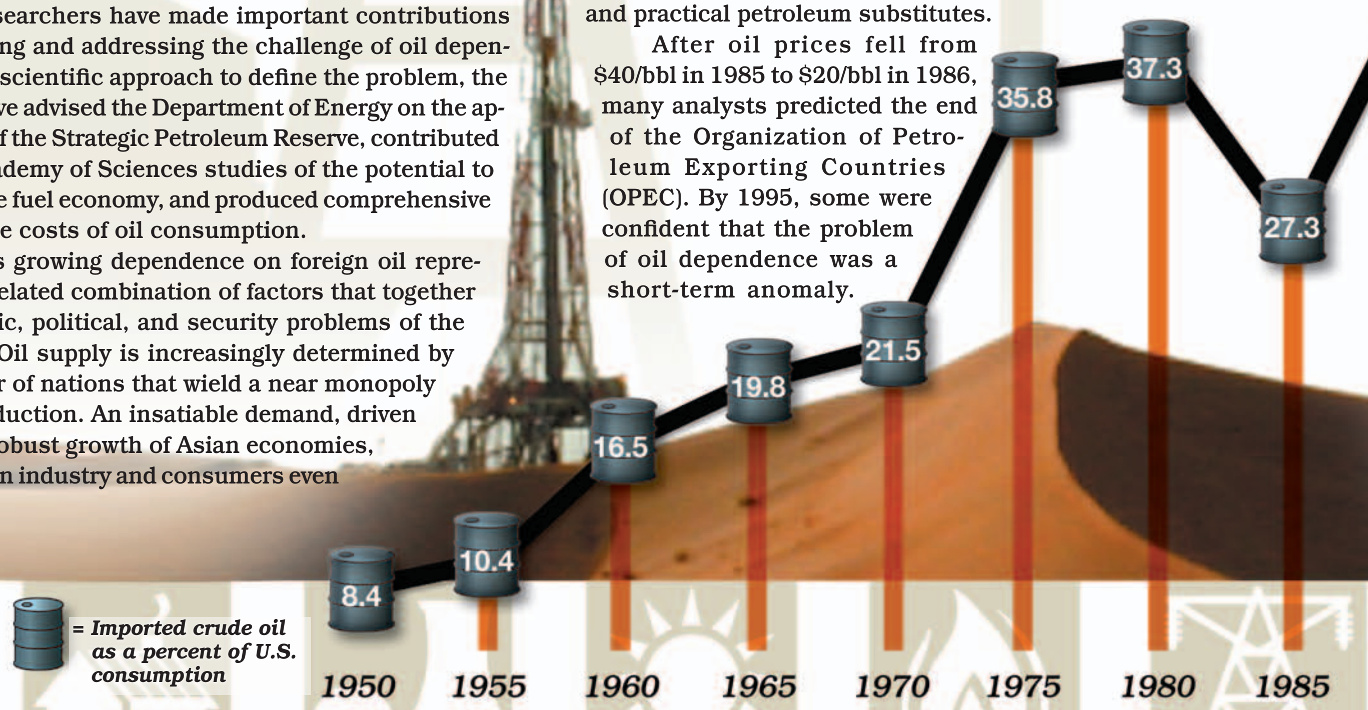
A 1995 ORNL model predicted an oil price shock for 2005 that hit the year before.

U.S. oil imports are at an all-time high, accounting for approximately 57% of domestic consumption. Americans today import some 12 million barrels per day at a cost that in 2004 skyrocketed above $50 a barrel.

ORNL researchers have made important contributions to understanding and addressing the challenge of oil dependence. Using a scientific approach to define the problem, the researchers have advised the Department of Energy on the appropriate size of the Strategic Petroleum Reserve, contributed to National Academy of Sciences studies of the potential to increase vehicle fuel economy, and produced comprehensive estimates of the costs of oil consumption.

America's growing dependence on foreign oil represents an interrelated combination of factors that together create economic, political, and security problems of the highest order. Oil supply is increasingly determined by a small number of nations that wield a near monopoly over world production. An insatiable demand, driven in part by the robust growth of Asian economies, makes American industry and consumers even more vulnerable to the recent shock of higher oil prices. Whether America can remove this vulnerability will depend on substantially reducing the volume of oil imported and consumed, an ambitious goal tied directly to making available affordable and practical petroleum substitutes.

After oil prices fell from $40/bbl in 1985 to $20/bbl in 1986, many analysts predicted the end of the Organization of Petroleum Exporting Countries (OPEC). By 1995, some were confident that the problem of oil dependence was a short-term anomaly.

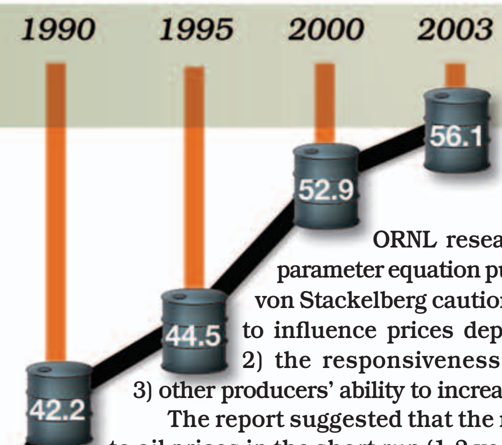


with a focus on efficiency standards for new construction and equipment rather than on expensive retrofits. In economic terms, many of these investments promise a net return in less than two years through reduced energy consumption.

For a variety of reasons, the United States must take the lead in developing technologies that make possible the opportunities for energy efficiency. The principal growth market for energy technologies and services in coming decades will be in developing countries. If American technologies dominate these markets, the U.S. economy will be the beneficiary. As a corollary benefit, the energy choices of developing countries will dictate trends in the world's environmental emissions. If their energy choices reduce the dependence of their growing economies on emission-intensive energy systems, the result will help make global environmental sustainability more achievable. Perhaps most important, energy policies in developing countries will have a direct impact upon America's political and strategic relationships with the rest of the world.

Even if the solutions are not yet available, the task ahead for the U.S. scientific community is clear. America's laboratories should aggressively develop better-performing, more cost-effective clean energy technologies to meet the needs of domestic and international economies. Using public-private partnerships, these technologies should be demonstrated both at home and abroad to showcase their viability and adapt them to the varying market demands of other countries.

Establishing American leadership in the development and implementation of innovative energy technologies will be a critical test for the U.S. scientific community. As researchers seek technological solutions, they must be aware that the issue of whether nations can provide energy services sufficient to sustain economic growth and political stability will be a dominant challenge to American foreign policy in the decades to come.—*Thomas J. Wilbanks, Environmental Sciences Division, ORNL.* Ⓡ



ORNL researchers disagreed. A three-parameter equation published in 1992 by Heinrich von Stackelberg cautioned that a producer's ability to influence prices depends on: 1) market share, 2) the responsiveness of demand to price and, 3) other producers' ability to increase supply when prices rise.

The report suggested that the market's ability to respond to oil prices in the short run (1-2 years) is about one-tenth of a long-run capability. OPEC could double, triple, even quadruple prices for 24 months but could not sustain such high prices for an extended period. Absent events such as military conflict, OPEC's only recourse to sustaining historically high oil prices is to cut production. Cutting production, however, would mean a loss of market share and thereby a loss of market power.

From 1979 to 1985 OPEC's share of the world oil market shrank from 50% to 30% as members (especially Saudi Arabia) continuously cut production to maintain high prices. But loss of market share did not alter the fact that OPEC members held 75% of the world's proven reserves and approximately 55% of the ultimate resources of conventional oil. Unless world oil demand could be curbed or economical substitutes to oil quickly developed, OPEC would inevitably regain lost market share. In 1999-2000, with help from Russia, Norway, and Mexico, OPEC engineered a doubling of world oil prices.

In a 1995 ORNL report, "The Outlook for U.S. Oil Dependence," Don Jones, Paul Leiby, and I simulated the impact of a two-year supply shock similar to those that occurred in 1973-74 and 1979-80, but starting in 2005 and ending in 2006. The model predicted that the shock would cause oil prices to jump from $20/bbl in 2004 to $50/bbl in 2005, costing the U.S. economy an estimated half a trillion dollars.

If the U.S. thirst for oil continues unabated, Americans increasingly will be forced to extract petroleum from unconventional sources. Oil sands and heavy oils are already in the early stages of exploitation in Canada and Venezuela. Continued demand will lead to oil shale, coal, or methane for liquid fuels. Such a path might allow OPEC to remain the lowest cost producer of oil and to sustain for several decades the capacity to supply a third or more of the world market.

The world could, of course, pursue a different path leading to low-carbon energy sources or even hydrogen fuel. Unfortunately, we do not yet know how to direct future energy transitions on the scale required for a global economy. Developing the right technologies is a critical but probably insufficient solution. These technologies would need to be accompanied by a fundamental rethinking, on an international level, of how we acquire, distribute, and use our planet's energy resources. *—David L. Greene, Engineering Science and Technology Division, ORNL.* Ⓡ

Aid for the Auto Industry

To reduce the use of imported oil for transportation and improve air quality, ORNL and UT researchers are conducting research that supports the design of cars and trucks that use fuel more efficiently.

Since the 1970s the U.S. government has supported research and development designed to help Americans use energy more efficiently. Because a large portion of American oil imports is used for transportation, the Department of Energy makes substantial investments at ORNL in several technologies designed both to improve fuel efficiency and reduce carbon emissions into the atmosphere.

The concept is simple in theory. In the near term, having an affordable supply of fuel requires that the next generation of cars and trucks burns fuel far more efficiently than these vehicles do today. In the long term, vehicles should burn a non-petroleum fuel, such as hydrogen (see p. 8). In addition to the economic and strategic benefits of a sustained domestic energy supply, these changes would be accompanied by reduced emissions of health-threatening air pollutants. Finally, efficient vehicles of the future should be made out of materials that are lighter than steel but at least as strong and stiff, to protect passengers during collisions.

Researchers with ORNL and with the National Transportation Research Center (NTRC) are working to help the transportation industry move toward these goals. Says NTRC Director Ed Grostick, "Our researchers are focused on practical technologies that are ready to be applied in the manufacture of new vehicles."

NTRC includes research staff from both ORNL and the University of Tennessee. A large portion of the research at the NTRC and ORNL is funded by DOE's Office of FreedomCAR and Vehicle Technologies.

Fuels and Engines

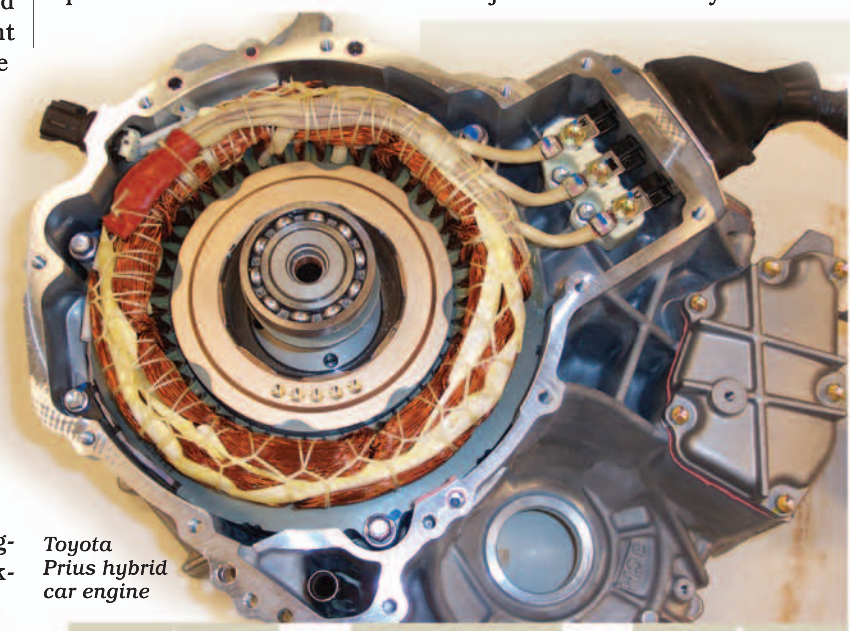
NTRC researchers are developing and applying new diagnostic tools and control strategies to help American automakers and engine companies improve the efficiency of internal combustion engines (ICEs), while simultaneously reducing their harmful exhaust emissions to levels so low they are difficult to measure. Because modern diesel engines are 30 to 50% more efficient than gasoline engines in cars and light trucks, NTRC researchers have set their sights on drastically reducing the emissions of nitrogen oxides (NOx) and particulate matter, which threaten respiratory health, so the vehicles will meet federal environmental standards and become more acceptable to American consumers.

For several years NTRC's Fuels, Engines, and Emissions Research Center (FEERC), led by Johney Green and Ron Graves, has focused research on emissions controls and catalyst-based after-treatment technologies for exhaust from diesel engines. Two unique FEERC inventions, the SpaciMS and a phosphor thermography instrument, were used together to map the dynamic, subtle changes in the chemical composition and temperature of emissions passing through a catalyst.

By combining FEERC's diagnostic tools with state-of-the-art electronic engine controls, the center's researchers are elucidating the interactions of exhaust species and the operation of lean-NO_X traps, a leading technology for controlling diesel emissions.

"In normal lean engine operation, lean NO_X traps store NO_X," Graves says. "A rich engine cycle supplies hydrocarbons in the exhaust that react with the NO_X on a catalyst to reduce it to nitrogen and other harmless byproducts. Controlling a diesel engine system so that it enters a rich regime without a driver noticing, while ensuring the generation of the right exhaust conditions for the NO_X trap, are tremendous challenges."

FEERC provided the first publicly available information on ways to operate diesel engines in low-temperature combustion modes that exhibit low NO_X and soot emissions simultaneously. Fully detailed emissions data, plus ways to maintain fuel economy in these low-temperature modes, are among FEERC's special contributions. The center has joined with industry in



Toyota Prius hybrid car engine

motivating the preparation of improved computational tools to simulate the operation of lean-burning engines and their emission control systems.

Power Electronics and Motors

Each of the three U.S. automakers plans eventually to manufacture hybrid gasoline-electric cars that are competitive with early models on the road today. According to Don Adams, director of NTRC's Power Electronics and Electric Machinery Research Center, ORNL researchers are developing power electronics and electric motors that could help U.S. automakers produce a less expensive, better performing, more reliable hybrid car.

ORNL researchers have helped develop or improve new types of electric motors that are simpler to control, lighter, and more powerful than those currently used in Japanese hybrid vehicles. All electric motors require some type of electronic drive, or inverter, to allow them to run at different speeds and power with the electricity generated by the engine or by braking. ORNL has teamed with industry to improve the inverter, enhancing its reliability and shrinking it from the size of a telephone booth to that of a telephone book.

ORNL research focuses on finding ways both to fabricate electronic devices that can withstand higher temperatures and to cool these devices more effectively. New materials becoming available, such as silicon carbide, can withstand much higher temperatures and be switched on and off faster, enabling better control of electric motors. If all the components in an inverter can be made to run at these higher temperatures, or if a better technique could be developed to spray a fluid on silicon devices and motors to cool them, then the hybrid car's cooling system could be decreased in size. The result would be a lighter vehicle and increased performance.

ORNL researchers are also working on developing smaller, lighter, and cheaper batteries and capacitors for storing more of the hybrid vehicle's electrical energy for longer times. All of this research could lead to a more affordable hybrid car.

More with Less

Making cars and trucks lighter is another important way to reduce fuel consumption. Phil Sklad, ORNL's technical program manager for both DOE's Automotive Lightweighting Materials and High Strength Weight Reduction Materials Technology Development areas, says the programs seek to identify materials and materials-processing technologies that can reduce vehicle weight.

One DOE goal is to reduce a five-passenger car's weight by half by 2010, maintain affordability, and increase the use of recyclable and renewable materials. Another DOE goal is to reduce the weight of trucks to increase fuel use efficiency.

"If the weight of a heavy truck is reduced using lighter but stronger materials, the truck can carry more freight," Sklad says. "A fully loaded truck cannot legally weigh more than 80,000 pounds. If trucks are made lighter, they can carry more payload. Thus, 9 trucks instead of 10 could legally carry the same total payload with a substantial reduction in fuel use."

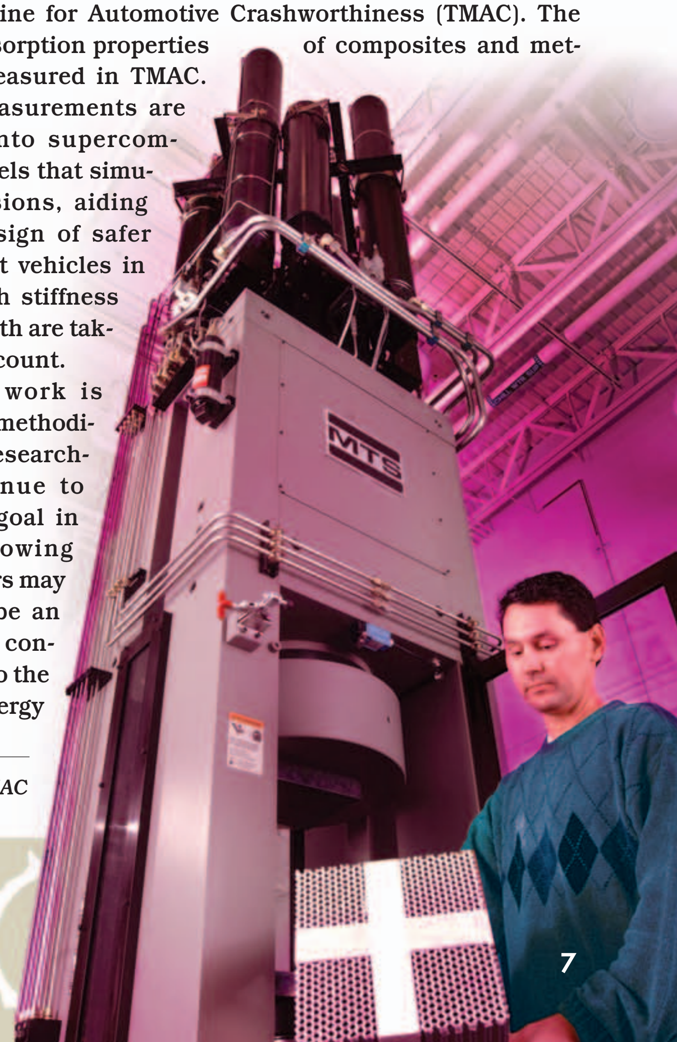
Over the years, heavy steel has been the dominant structural material in vehicle frames and other components. The automotive industry is already replacing some parts made of regular steel with parts fabricated from aluminum, magnesium, glass composites, carbon-fiber composites, and advanced high-strength steel. The newer steel is tailored to promote a microstructure that gives elevated properties, allowing the use of thinner, lighter sheets of the material for automotive structures.

The program Sklad heads has found that each material has both advantages and drawbacks. "If you replace the steel in a car with carbon-fiber composites, you reduce the vehicle's weight by about two-thirds," Sklad says. "But cost remains a barrier. The automotive industry will not replace steel with carbon fiber until the cost of the fiber is reduced to $3 to $5 a pound."

ORNL researchers Alicia Compere and Bill Griffith, along with their collaborators at UT and North Carolina State University, are pursuing a way to make carbon fiber for less than $5 a pound, a dramatic drop from the $8 a pound cost of commercially produced carbon fiber made using petrochemicals. The ORNL-university technology is based on producing fibers in a size range suitable for automotive and aerospace composites by "melt-spinning" them from a blend of pulp-mill lignin—a waste product of the paper industry—and recycled plastic.

Carbon-fiber composites have been "crushed" at NTRC's Test Machine for Automotive Crashworthiness (TMAC). The energy absorption properties of composites and metals are measured in TMAC. These measurements are entered into supercomputer models that simulate collisions, aiding in the design of safer lightweight vehicles in which both stiffness and strength are taken into account.

The work is slow and methodical, but researchers continue to keep the goal in sight, knowing the answers may someday be an important contribution to the world's energy needs. ®



The TMAC

Multiple Roads to the Hydrogen Car

ORNL is conducting research on hydrogen production, distribution, safety, and fuel cells for our children's cars.

In his 2003 State of the Union address, President George Bush communicated an ambitious vision that the United States will lead the world in developing clean, hydrogen-powered automobiles.

"The hydrogen economy at a minimum is 20 years away," says Tim Armstrong, manager of the Hydrogen, Fuel Cells, and Infrastructure Program at ORNL. "The big scientific challenges are hydrogen generation and distribution, hydrogen storage, and fuel cell durability."

The Laboratory is a leader in separation technologies for producing hydrogen. ORNL is the lead Department of Energy laboratory in studying hydrogen delivery and ranks third in DOE funding for research on vehicular fuel cells.

To produce hydrogen, ORNL is developing both microporous and proton separation membranes supported on porous metallic tubes. These membranes could separate hydrogen from carbon monoxide in syngas produced by coal gasification. The microporous membrane is derived from the declassified inorganic membrane developed to enrich uranium in its fissionable isotope at the old Oak Ridge Gaseous Diffusion Plant. A team led by Armstrong has developed a new proton conductor, a ceramic oxide, that enables hydrogen to diffuse rapidly through it at temperatures less than 700°C, where most conventional proton-conducting oxides operate. "Our material works at 500°C," Armstrong says. "This is the 'sweet spot' for separating hydrogen from coal gas."

Hydrogen also can be produced from natural gas and petroleum. To generate pure hydrogen, sulfur must be removed from these fossil fuels. ORNL and DOE's National Energy Technology Laboratory have developed a way to remove sulfur from hydrogen sulfide (H_2S) gas streams using a carbon-based catalyst. The ORNL catalyst can remove both carbonyl sulfide (COS) and H_2S, making it ideal for separating sulfur from coal gas; the sulfur-free gas can be a source of pure hydrogen for fuel cells. This sulfur-removal method has attracted the interest of General Electric, ChevronTexaco, and ConocoPhillips.

A team led by ORNL's James Lee seeks to produce hydrogen biologically. The project focuses on engineering wild algae's genetic structure and adding a proton channel to increase the algae's hydrogen production efficiency 10 to 100 times, possibly creating a renewable hydrogen resource.

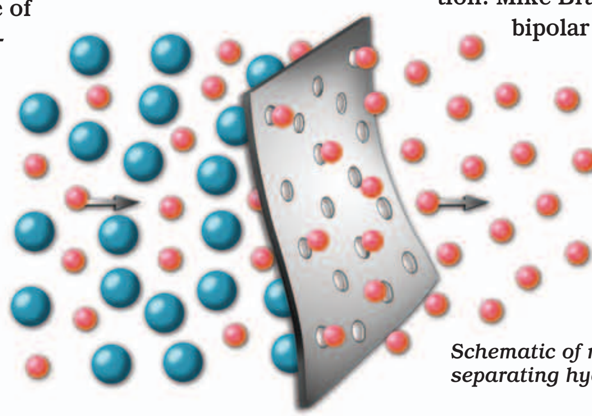
For hydrogen delivery, ORNL researchers are developing and examining materials for pipes and welds that exhibit a very low hydrogen diffusion, or leak rate. The goal is to replace today's current natural gas pipeline materials with metallic systems and to improve welds, which are potential failure points in pipelines.

A new ORNL project would reduce the number of welds by adding distance between them while simplifying the assembly process. The goal is to develop a "smart" pipeline consisting of an extruded polymer pipe liner reinforced by a carbon fiber tow. The tow is integrated with leak sensors and failure sensors before being wrapped.

Jim Hardy's team at ORNL is developing a cost-effective, portable acoustic sensor to detect leaks from hydrogen gas pipelines. The researchers are also developing a fiber-optic–based hydrogen safety sensor that will monitor the pressure of compressed hydrogen in the fuel tanks of future fuel-cell–powered vehicles.

ORNL's Tim McIntyre leads a team devising a fiber-optic–based sensor to monitor the temperature and humidity in fuel cells. Measurements of inlet and outlet gas parameters will be used to validate computer models of fuel cell performance. These sensors will become an integral part of a fuel-cell control system.

Recently, a carbon-based bipolar plate developed by ORNL's Ted Besmann was licensed to Porvair for commercialization. Mike Brady has since developed a new metal bipolar plate for proton-exchange-membrane (PEM) fuel cells. "The plate has very high electrical conductivity and has shown no corrosion up to 5000 hours," says Armstrong. "We are partnering with fuel-cell manufacturers and automakers to develop further this and other ORNL technologies." Ⓡ



Schematic of molecular sieve membrane for separating hydrogen from mixed gas streams

Closer to the Customer

ORNL helps bring reliable, energy-efficient cooling, heating, and power to commercial customers nationwide.

Without warning, the August 14, 2003, power blackout removed electricity for millions of people in the United States and Canada. The next day manufacturers still had no power, contributing to an estimated cost to the U.S. economy of $6 billion. Meanwhile, in Ontario, New York, Harbec Plastics, which machines complicated plastics parts, operated during the blackout without interruption, owing to an array of 25 Capstone microturbines. Fired by natural gas, each microturbine produces 30 kilowatts (kW) of electricity and virtually no pollutants. The array's waste heat is recovered and used both to heat water and air (in winter) and cool the building space in summer.

Typically, about two-thirds of the fuel energy used to generate electricity in central power stations is discarded as waste heat and then as losses incurred in power transmission and distribution. By the time the power reaches the point of use, total efficiency can drop to 30%. However, efficiency can be raised to more than 70% by locating each power source close to the customer and productively using the source's waste heat for heating, cooling, and controlling humidity in each appropriately sized commercial or institutional building. Since the 1990s the Department of Energy and the private sector have worked together to develop such distributed energy (DE) technologies, also called cooling, heating, and power (CHP) units and, more recently, integrated energy systems (IES).

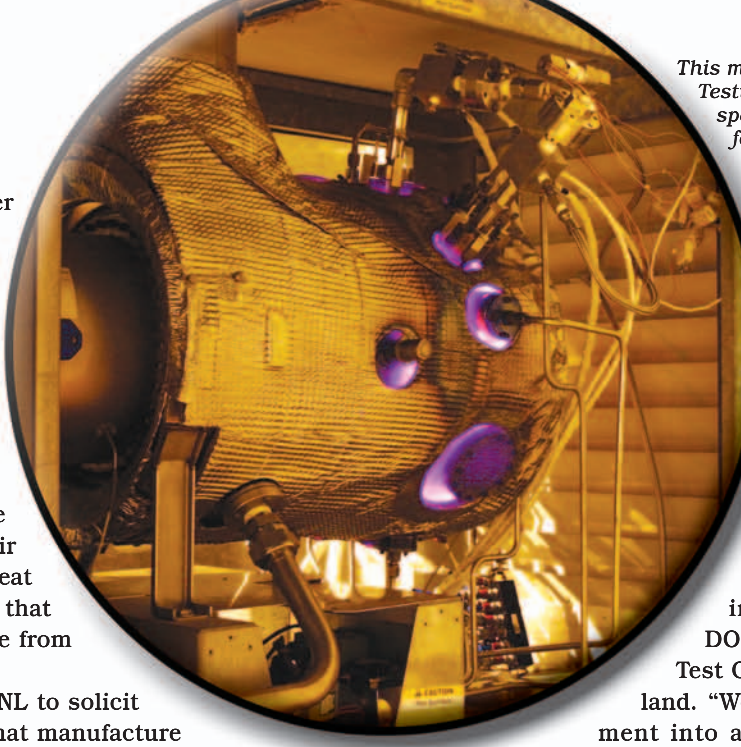
DOE is seeking to demonstrate that IES units in operation throughout the United States can increase the nation's energy efficiency, reliability, and security, reduce dependence on imported oil, and simultaneously lower emissions of pollutants that threaten health and a stable climate. DOE's goals are to develop the next generation of clean, efficient, reliable, and affordable DE technologies, integrate these technologies into appropriately sized end-use sites, and capture waste heat, or thermal energy, to more than double energy efficiency for heating and cooling of buildings.

Ready for Prime Time

DOE asked ORNL to focus on three types of energy sources, or "prime movers," for IES units: industrial gas turbines, reciprocating engines, and microturbines. All of these sources can burn natural gas and produce two types of energy: electricity and waste heat. These sources would be integrated with a "thermally activated" technology, such as an absorption chiller for cooling, a desiccant wheel for dehumidification, or a steam generator or heat exchanger for heating water or air.

ORNL supported the development by UTC Power, a United Technologies Company, of the UTC PureComfort™ system, a reliable IES with ultra-low emissions that features a 112-ton absorption chiller powered by waste heat from four to six 60-kW microturbines. The double-effect chiller provides cooling and heating from the same unit, conserving space and simplifying design. In summer the chiller uses waste heat from the microturbine as the source of energy for driving the fluid that extracts heat from water to chill and provide air conditioning. The CHP technology has an efficiency of up to 80%.

ORNL researchers have teamed with industrial partners to figure out how to capture heat from each turbine or engine and transfer the heat to a thermally activated system to provide cooling, dehumidification, or heating. ORNL's Jim Sand has promoted the use of waste heat for dehumidification in schools and other buildings to improve air quality and prevent



This microturbine in the ORNL Recuperator Testing Facility is used to test metal specimens to determine their suitability for high-temperature recuperators.

the growth of mold and other allergens. Waste heat from engines and turbines can be combined with a desiccant system to create a more comfortable environment where temperature and humidity are controlled independently. Air can be passed through a desiccant wheel, which absorbs the moisture and sends the resulting dry air into the building. The waste heat dries the desiccant wheel so that it can again pick up moisture from indoor air.

In 2001 DOE asked ORNL to solicit proposals from companies that manufacture engines, turbines, and heat exchangers, as well as from end users that can benefit from IES units. ORNL personnel served as technical project managers in cost-shared contracts between DOE and industry, which bore 43% of the cost. The ORNL project managers provided technical expertise to the industrial partners and helped identify the best ways to capture waste heat for making what the end user wanted, such as chilled water for air conditioning or heat for steam. By 2004 several partners had met the DOE goal of combining individually optimized products on-site.

One project at a hospital and strategic command center at Fort Bragg Army Base in North Carolina included a gas turbine, absorption chiller, steam generator, and Honeywell control system that constantly provides power, heating, and cooling. A second project was a gas turbine that provides both electricity and chilled water for air conditioning to the tenants of an Austin, Texas, industrial park. A third was a project in New York where a skid-mounted UTC PureComfort 240 system was installed on the roof of an A&P Supermarket. The system supplies electricity and chilled water year-round for the supermarket's refrigeration cases. Waste heat is also used to heat the supermarket in the winter months.

The DOE goal for 2010 is that each manufacturer would produce a single optimized IES package because each integrated or modular IES package will be more cost effective, require little on-site engineering, and offer a higher overall energy efficiency. By 2010 DOE hopes to show that single optimized IES packages can meet targets of a 32% reduction in energy usage and a 46% reduction in carbon dioxide emissions. ORNL is contributing to this effort by helping with integration, size reduction, and packaging of CHP technologies to improve energy efficiency.

ORNL researchers are also working with industrial partners to oversee the design, development, installation, and operation of IES units in larger market sectors such as hotels, supermarkets, hospitals and medical centers, movie theaters, and high schools and colleges. In 2004 the ORNL researchers—Randy Hudson, Jan Berry, Jim Sand, and Therese Stovall—began monitoring and collecting data on the operation of the newly installed IES units throughout the country.

Research Payoffs

Patti Garland, an ORNL engineer and CHP program manager, has been a principal investigator for experiments at DOE's Integrated Energy Systems Test Center at the University of Maryland. "We integrated off-the-shelf equipment into an IES unit at the university's Chesapeake Building," she says. "This building, which is occupied by more than 150 people, has four miles of cables and more than 190 data points from which we measure real-time operating performance of the test equipment. We conducted performance testing on the IES there, collected data, made some mistakes, and, based on the lessons we learned, provided recommendations to industry on how to improve designs of IES equipment. A valuable recommendation was to install an airtight damper to isolate the microturbine exhaust from the absorption chiller when the chiller is not operating."

According to Bob DeVault, the highly instrumented CHP laboratory at ORNL where he works was the first lab to test both a microturbine and heat exchanger simultaneously and as a system over the whole range of thermal conditions. Neither the microturbine vendor nor the heat exchanger manufacturer is set up to conduct the types of tests that ORNL can do.

The ORNL research should help industry and DOE meet two goals by 2010. The first goal is to double the amount of CHP capacity in the United States, bringing it to 92 gigawatts of installed capacity. The second goal is to build and install packaged systems with an energy efficiency of at least 70% and a payback of 4 years or less—that is, the amount of money saved by reduced demand for energy would cover each system's additional capital cost in no more than 4 years.

According to Dave Stinton, a manager of ORNL's Distributed Energy Program, ORNL researchers have been developing advanced materials to increase the efficiency of engines and turbines. They have been evaluating the longevity of continuous fiber-reinforced ceramic composites used in combustor liners and the oxide coatings that protect these liners against oxidation in industrial gas turbines built by Solar Turbines, Inc.

"We also conduct research on natural-gas-burning reciprocating engines in collaboration with Caterpillar, Cummins, and Waukesha," Stinton says. "Reciprocating engines are more efficient than gas turbines and microturbines but have higher emissions of nitrogen oxides (NO_X). Our challenge has been

to reduce emissions from the engine by an order of magnitude and increase the efficiency to 50%."

"We have developed a NO_x trap that reduces the NO_x emissions from lean-burn engines to 0.1 g/hp/hr, meeting the goal of the program for 2010, " says Tim Theiss, manager of ORNL's Advanced Reciprocating Engine Systems Program.

ORNL researchers are working in partnership with industry to extend the life of spark plugs for natural gas–fired reciprocating engines to 8000 hours, delaying the need for maintenance from several months to one year. Laboratory staff who collaborate with Federal Mogul, makers of Champion spark plugs, believe that use of alternative materials will result in a cheaper, more durable, corrosion-resistant spark plug.

ORNL is now working with Capstone, UTC, and General Electric with a goal of raising the efficiency of microturbines from 27% to 40%. "The ability to operate a microturbine at higher and higher temperatures will lead to higher efficiencies, but this operating level will be possible only with the right materials," says ORNL's Edgar Lara-Curzio. "We have been screening and evaluating materials for a microturbine component that is responsible for one half of the microturbine's efficiency. We selected an innovative approach for screening and evaluating candidate materials that should enable us to identify the right materials for the hot section and recuperator of an advanced microturbine."

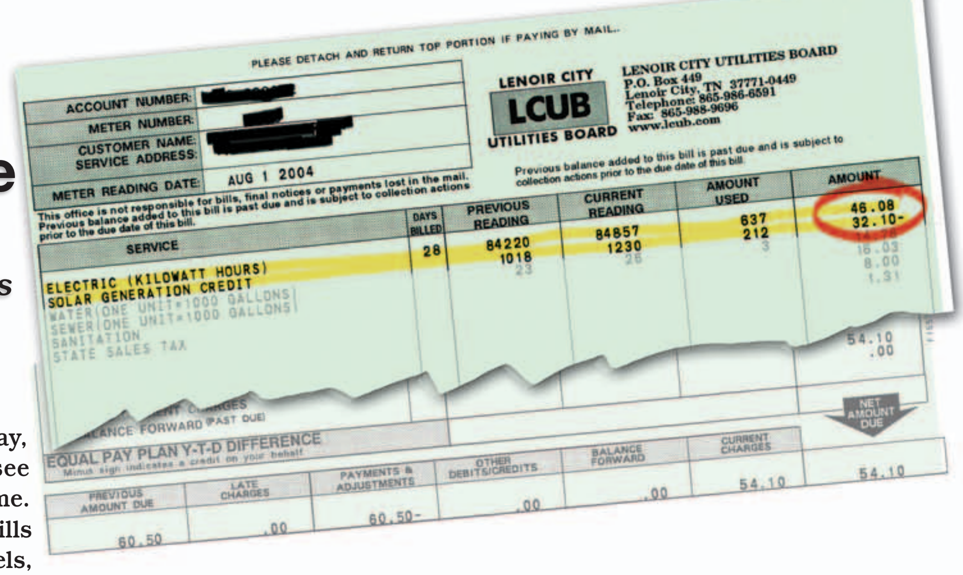
"What we are trying to do in the short term is use better metals to get the hot section up to an intermediate temperature range," Stinton says. "Capstone's beta version of a metal microturbine demonstrates 34% efficiency.

"We are looking at silicon nitride for a microturbine's rotor, the hottest part of this machine. Use of a ceramic rotor would raise the turbine inlet temperature by several hundred degrees Celsius, boosting the microturbine's efficiency to nearly 40%."

As a result of the latest solicitation, ORNL is involved in IES projects not only with hotel and supermarket chains but also with Wal-Mart stores and McDonald's restaurants. These projects offer potential for reliable, as well as efficient, energy sources. In 2003 a new IES protected the critical circuits of the Hilton Garden Inn in Chesterton, Indiana, when a violent thunderstorm caused a four-hour electrical outage in the area. The hotel's guests enjoyed normal operations including a hot lunch during the outage.

"These partnerships are exciting because they should enable a new technology to be replicated nationwide," Stinton says. "IES units already are cost effective in many parts of the United States. We are very enthusiastic about the potential of this technology as one solution to America's energy challenge." Ⓡ

ORNL researchers will evaluate integrated energy system projects at Wal-Mart stores.


PLEASE DETACH AND RETURN TOP PORTION IF PAYING BY MAIL.

ACCOUNT NUMBER: [redacted]
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CUSTOMER NAME: [redacted]
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SERVICE	DAYS BILLED	PREVIOUS READING	CURRENT READING	AMOUNT USED	AMOUNT
ELECTRIC (KILOWATT HOURS)	28	84220	84857	637	46.08
SOLAR GENERATION CREDIT		1018	1230	212	32.10-
WATER (ONE UNIT=1000 GALLONS)		23	26	3	14.78
SEWER (ONE UNIT=1000 GALLONS)					16.03
SANITATION					8.00
STATE SALES TAX					1.31
					54.10
					.00

BALANCE FORWARD (PAST DUE)
EQUAL PAY PLAN Y-T-D DIFFERENCE
Minus sign indicates a credit on your behalf

NET AMOUNT DUE

PREVIOUS AMOUNT DUE	LATE CHARGES	PAYMENTS & ADJUSTMENTS	OTHER DEBITS/CREDITS	BALANCE FORWARD	CURRENT CHARGES	
60.50	.00	60.50-	.00	.00	54.10	54.10

Pushing the Envelope

A promising example of ORNL's work on integrating building technologies is progress in creating affordable zero-energy houses.

If ORNL's Jeff Christian could have his way, next-generation houses in East Tennessee would generate as much electricity as they consume. Such zero-energy homes, which eliminate electric bills by producing the power they need using solar panels, would be modeled after the four near-zero-energy Habitat for Humanity houses built in 2002-2004 near Lenoir City, Tennessee.

The master builders of the village are volunteers and researchers with the Department of Energy's Buildings Technology Center (BTC), which Christian leads. DOE and the Tennessee Valley Authority (TVA) jointly fund the program. The houses are the culmination of ORNL research for DOE on building envelopes, including roofs and walls, as well as appliances, such as refrigerators and systems for heating and cooling air inside buildings.

"The average daily energy bill for these houses is less than a dollar, possibly as low as 65 cents, for the most efficient house over time," Christian says. "The fifth and last house will take advantage of the latest energy-efficient technologies and lessons learned from the construction, monitoring, and analysis of the four near-zero-energy houses."

For each test house, the insulated metal roof assembly has three jobs: it provides enhanced moisture control using a drained layer, insulation for the residents, and electricity for the grid. Each roof has solar panels, with the electricity produced from the panels' photovoltaic cells sold to TVA's Green Power Generation Partnership Program. The electric bill for each house is exceptionally low, based on the power used for the house minus the credits TVA gives for the power generated by the solar panels for distribution on TVA power lines.

A data system that charts energy usage, temperatures, and flow of water and electricity for each house indicates that these houses use 50 to 70% less energy than typical new American homes.

The secret behind each house's exceptional energy efficiency lies in a well-insulated airtight envelope. The walls and roof incorporate structural insulated panels (SIPs) that keep indoor heat in during winter and outdoor heat out during summer. The SIPS in the fourth house, which contain pentane-blown polyisocyanurate insulation, minimize damage by moisture and, combined with integrated window wall panels, reduce losses of inside air already heated or cooled to comfortable living temperatures.

During Tennessee's cold season the house's thermal mass foundation walls store heat absorbed from the sun during the day and release the heat to the house interior at night. The air ducts are positioned inside the conditioned space, as recom-


Jeff Christian in one of the Habitat for Humanity near-zero-energy homes in Lenoir City, Tennessee

Courtesy *Mother Earth News*/Allan B. Hunt

Letting the Sunshine In

The outlook is sunny for the Laboratory's prospects of commercializing hybrid solar lighting (HSL). The ORNL technology uses sunlight to reduce the need for indoor electric lighting, the largest consumer of electricity in commercial buildings.

A rooftop HSL system collects, concentrates, and transmits sunlight through optical fibers to hybrid light fixtures inside the building, which also contain high-efficiency fluorescent lighting. When the transmitted sunlight completely illuminates each room, the electric lights stay off. When less natural light is available during cloudy days and at night, a photosensor activates dimmable controls that increase electric lighting adequately to supplement natural lighting and maintain desired illumination levels.

Utility bill shows August 2004 electricity cost for a near-zero-energy house was only $13.98, thanks partly to rooftop solar panels.

mended by ORNL research, providing 30% to 40% space heating and cooling energy savings.

Each house has efficient heating, ventilation, and air conditioning equipment, as well as highly efficient appliances. To keep residents comfortable, each super-efficient house has a heat pump, including a geothermal heat pump in the third house.

The fourth house has an integrated drop-in heat pump water heater, mechanical ventilation (to circulate fresh air in the airtight structure), and appliances rated at some of the highest efficiencies possible.

Other energy-saving technologies in the houses are compact fluorescent light bulbs, high-efficiency windows, and extended roof overhangs on the south side to shade the top-floor windows during the summer. The houses also contain sensors and controls to ensure that the mechanical ventilation system is providing airflow at rates that meet national standards.

Because of the more-efficient appliances and better photovoltaic system on the roof, the second- and third-generation test houses use about 20% less energy and produce about 11% more solar electricity than the first.

"We are building one more house that will be outfitted with energy-saving technologies," Christian says. "Based on analysis of the data we get from all the houses, we plan to determine the most cost-efficient methods of saving energy in houses and assembling small, well-crafted houses. The ultimate goal is the creation of zero-energy homes that are affordable to most Americans."

Integrating Building Technologies

Patrick Hughes, ORNL's Building Technologies Integration Manager, says DOE's Building Technologies (BT) Program, the foundation sponsor for ORNL's buildings research, is calling for integration of buildings technologies. "As Jeff Christian's Habitat for Humanity project illustrates, ORNL is well positioned to integrate building technologies to foster their advancement, transfer, and deployment. ORNL will continue to develop new and exciting technologies to integrate into buildings in the future."

Four groups in ORNL's Engineering Science and Technology Division—Building Equipment, Building Envelope, Residential Buildings, and Commercial Buildings—are developing breakthrough building technologies. For example, to help make thermal mass more available for mass market construction, ORNL researchers seek to increase the effective thermal mass in the insulation cavity through use of phase change material (PCM)-enhanced fiber insulation. To make SIPs less susceptible to termites, rotting, and warping, Laboratory researchers are working with industry to develop SIPs with steel instead of processed-wood facings. The new SIPS would also exhibit improved wind and fire resistance, dimensional stability, and energy savings. ORNL researchers are working on the development of an integrated residential heat pump that provides hot water, space heating, cooling, ventilation, and dehumidification. Combining experiments with computational modeling, ORNL, in partnership with industry, is improving air curtain design to reduce energy use by refrigerated display cases in supermarkets and other food retail outlets.

Other technologies under development include an advanced, low-cost geothermal heat pump, a lower-cost version of the heat pump water heater invented by ORNL researchers and industry, and low-cost sensors for adaptive controlled ventilation that could be tied into an energy management control system that turns off lights, air handlers, and other unneeded energy-consuming equipment in buildings.

By combining their efforts with those of a variety of partners, ORNL scientists anticipate a growing integration of energy-saving ideas with construction technologies. ®

Jeff Muhs

Principal investigator Jeff Muhs, of the Advanced Laser, Optics, and Diagnostics Technology Group in ORNL's Engineering Science and Technology Division, spearheaded the development of this revolutionary solar technology. Muhs organized a Hybrid Lighting Partnership, a collaboration of more than 25 organizations in 13 states, to assist in the research. In 2003, the group hosted the first Annual Hybrid Solar Lighting Summit, which was attended by both public and private stakeholders, including architects, utility executives, lighting designers, green power and clean energy advocates, and prospective commercialization partners.

ORNL also organized a broad-based public-private alliance to carry out the research and development needed to make HSL a viable commercial technology. Alliance members include, in addition to ORNL, the Tennessee Valley Authority (TVA), Wal-Mart, the Sacramento Municipal Utility District (SMUD), JX Crystals, SAIC, 3M, Honeywell, ROC Glassworks, Array Technologies, Edison Electric Institute, several prominent universities, and other national labs.

Under a contract awarded by the California Energy Commission, ORNL and SMUD in 2005 will install and begin operating an HSL system at SMUD's Sacramento headquarters. ORNL also plans to install an HSL system in a Wal-Mart store in Kauai, Hawaii, to evaluate energy savings and sales trends associated with HSL daylighting.

TVA and DOE are funding new R&D work on HSL lighting fixtures, or luminaires, that combine electrical lamps and optical fibers. The latest luminaires will be part of an HSL display at Oak Ridge's American Museum of Science and Energy in 2005.

Industrial Efficiency

ORNL is contributing new technologies, materials, software tools, and training to improve the energy efficiency of American industry.

Improving the efficiency of manufacturing processes is an important component of ORNL's energy mission. Over the years Oak Ridge materials researchers have pursued this goal for a variety of industries through the Department of Energy's Industrial Technologies Program (ITP). ORNL researchers are developing highly energy-efficient industrial processes, materials that help improve energy efficiency, software tools, training for industrial engineers who work for companies of all sizes, technical fixes, and improved procedures.

Hot Projects

A recent notable achievement in ORNL's Industrial Technologies Program, led by Peter Angelini of the Laboratory's Energy Efficiency and Renewable Energy Program Office, offers considerable potential to reduce energy use in a variety of industries. In 2004 seven ORNL researchers and their project partners received an R&D 100 Award from R&D magazine—one of 100 top innovations of the year—for developing an Advanced Heating System. "Queen City Forging Company of Cincinnati is testing the Advanced Heating System and has used the process to produce thousands of pounds of material," Angelini says.

The ORNL researchers responsible for this development are led by Craig Blue of ORNL's Metals and Ceramics (M&C) Division. The project partners are the Forging Industry Association of Cleveland; Komtek of Worcester, Massachusetts; Queen City Forging Company of Cincinnati; Boston's Northeastern University; and Infrared Heating Technologies of Oak Ridge.

The Advanced Heating System uses an optimized combination of radiant and convection heating for processing materials. When used to heat aluminum billets, the system greatly reduces heating time and energy consumption. The process also produces high-performance forgings with significantly improved tensile and fatigue properties, compared with those heated by conventional techniques.

"We found that rapid heating greatly improves the microstructural and mechanical properties of aluminum before it is forged into parts susceptible to fatigue because of high thermal cycles," Blue says. "As a result, less scrap is produced. Because heat treating an aluminum part using both infrared and convection heating takes much less time than processing the part in a conventional convection furnace, our system is three times more energy efficient. The Advanced Heating System also could be used in other thermal processes, including joining and heat treatment, and can be tailored to process steel, titanium, and nickel-based alloys."

Another energy-saving achievement for industry at ORNL has been the development of a high-performance, chromium-tungsten steel by Ron Klueh, Vinod Sikka, Phil Maziasz, Mike Santella, and Suresh Babu. This material could be used in pressure vessels for petrochemical plants. "A lot of these vessels must be heat treated to make them reliable," Angelini says. "Vessels made of the ORNL steel might not need heat treatment, saving considerable energy. As a bonus, the ORNL steel, which transfers heat more efficiently than conventional vessel materials, is 50% stronger, lighter, and easier to handle."

Each year Caterpillar uses 15 million pounds of steel weld wire to manufacture earth-moving equipment. The company wishes to reduce its needs for welding to save energy. One problem is that some welds do not last very long because of residual stresses and deformation, so additional wire is needed to repair those welds. In an ORNL-Caterpillar project on virtual weld-joint design, Suresh Babu, Andrew Payzant, and a team including Caterpillar researchers developed an integrated material model that predicts performance of welds formed from different alloys. The model's results suggested Caterpillar should use weld wire made of a different steel. Preliminary results indicate that Caterpillar's future weld joints may last 10 times longer than the current ones, possibly reducing its energy use by 25%.

Best Practices

In an era of increasingly tight profit margins, opening lines of communication between industry and government energy experts has boosted some companies' bottom lines. Forward-thinking U.S. industrial manufacturers acutely aware of rising energy prices are seeking assistance from ORNL engineers on how to increase energy efficiency and productivity in their plant operations while decreasing pollutant emissions and production of scrap.

BestPractices, a program of DOE's Industrial Technologies Program that ORNL researchers help execute, enables industry to identify plant-wide opportunities for improving energy savings and process efficiency. Through the implementation of new technologies and systems improvements, companies across the United States are achieving immediate savings, helping to create new jobs and maintain current ones.

American industries benefiting from the services of BestPractices reduced their use of energy in fiscal-year 2003 by 20 trillion to 40 trillion British thermal units (BTUs). These services were provided largely by the Industrial Energy Efficiency Group in ORNL's Engineering Science and Technology Division. The group's leader is Mitchell Olszewski, a mechanical engineer. ORNL first became involved in 1995 when MotorMaster+ was being launched by the Motor Challenge Program. The program's software tool and database enabled U.S. industry to track the whereabouts of existing motors of different powers and decide whether to repair or replace specific motors.

By 2000 the motor program had evolved into BestPractices. "We recognized that the real energy savings in an industrial plant come from improvements in systems of connected components more than in individual components," Olszewski says. "More energy is used on the thermal side than the electrical side, so we began looking at steam and process heat as well as motors, pumps, fans, and compressed air systems.

The ORNL group provides technical assistance to a company team tasked by management to conduct a plant-wide assessment to identify energy efficiency opportunities. DOE pays half the assessment's cost, up to $100,000, for industries the agency has supported since 2000: agriculture, aluminum, chemicals, forest products, glass, metal casting, mining, petroleum, and steel. In the past year ORNL researchers have been allowed to branch out to other energy-intensive industries. "We have done energy assessments in the food processing, cement, and automotive industries," Olszewski says. "We particularly want to work with plants that have high energy bills and that are part of multi-plant corporations. Our goal is to have our successes in improving energy efficiency in an industry multiplied many times."

The ORNL group has developed software tools for industry in process heating units and in pump, steam, fan, compressed air, and chiller systems. "These tools are designed to give plant engineers a quick understanding of whether a large payoff is possible by identifying energy efficiency opportunities," Olszewski says. "The plant engineers can determine which systems should be examined in detail. Equipped with this information, they can decide with confidence that a serious opportunity exists to invest in changes that will improve energy efficiency and lower costs."

For example, a plant manager using the pump system assessment tool can determine within a day or two the few pump systems (generally a half dozen or so out of a population of hundreds or thousands) that offer substantial energy-saving opportunities. Investment decisions regarding how to capture the opportunities can then be focused on a limited and manageable number of systems.

To help plant engineers learn how to use the tools, ORNL offers end-user training sessions in pumps, motors, fans, and steam, compressed air, and heating systems. "We give 50 sessions a year and the typical attendance is 30 people per session," says Olszewski. "Each session describes commonly found situations that reduce the performance of the system. We then demonstrate how the ORNL tool helps the user identify the existing energy efficiency opportunities for that system. Each primer tells plant engineers what the tool will do for them and how they can use it." The ORNL group also trains engineers who desire to be qualified specialists in the use of a particular software tool.

Queen City Forging Co. is testing a prize-winning process.

Courtesy Queen City Forging

In the years ahead, one fact is certain. The rising cost of energy will place a premium on finding an ever-increasing number of ways to maximize the efficiency of America's manufacturing sector. Additional information is available on a web site maintained by DOE: www.oit.doe.gov/bestpractices/ Ⓡ

More Power to the GRID

Working with industry, ORNL is testing advanced conductors and developing superconducting cables to improve the efficiency of the U.S. electric grid.

On August 16, 2004, a year and two days after the largest power blackout in U.S. history, 3M announced the first commercial sale of an advanced conductor for overhead power lines. This conductor, if put into widespread use, could greatly reduce the probability of blackouts while carrying at least double the electrical current. Xcel Energy will give 3M's ceramic-core conductor its first commercial application in 2005 when the conductor is installed on a 10-mile transmission line in Minnesota.

John Stovall, Roger Kisner, and Tom Rizy, researchers in the Cooling, Heating & Power Group in ORNL's Engineering Science and Technology Division, are excited about this sale. For two years, they have field-tested the high-temperature 3M conductor, the core of which consists of ceramic Nextel™ fibers enveloped in an aluminum-zirconium matrix.

Recently, the tests have been conducted at the Powerline Conductor Accelerated Testing (PCAT) facility, part of the National Transmission Technology Research Center. NTTRC, jointly supported by the Department of Energy and Tennessee Valley Authority, was established at ORNL to evaluate conductors and high-voltage power electronics in response to DOE's National Transmission Grid Study, issued in May 2002. In that document DOE named advanced conductors as a key enabling technology for upgrading the national electricity transmission system.

Superconducting cable

Transmission Tests

Tests at the NTTRC demonstrated that the 3M composite conductor can carry 1.5 to 3 times the current of conventional steel-core, power-line cables at the same voltage. The tests also showed that the conductor and its accessories can withstand extreme heat. Tests in other U.S. locales indicated that the 3M conductor holds up better when subjected to high winds, vibrations, salt corrosion, and extreme cold than do the heavier lines, 20 to 50 years old, that are threaded through transmission corridors nationwide. These advantages make the new conductor ideal for seacoast installations. The results have been good news for 3M, which invented the conductor to eliminate transmission bottlenecks that contribute to brownouts and blackouts.

One major transmission problem has been power-line sag. When hot weather generates demand for more electricity for air conditioning, power lines heat up, stretch, and sag. If an overloaded line sags into a tree, the current can be discharged to the ground, causing a short circuit and sometimes triggering a major power outage. Sag was a cause of the two major U.S. blackouts in 1996 and 2003.

"We found that the 3M conductor's sag at a rated operating temperature of 210°C will be the same as that of a standard steel line at the rated operating temperature of 100°C," Stovall says. "Effectively, the 3M conductor has less sag at the temperature allowed for operation of conventional power lines.

Utilities may be reluctant to install 3M conductors because they cost more than steel-core lines. "But if a utility wants to move twice as much electrical current between point A and point B," Stovall says, "replacing a steel-core line with a high-temperature 3M conductor is cheaper and easier than acquiring a new right-of-way in a transmission corridor and installing a second set of transmission towers for an additional conventional line."

Superconductivity and Transmission

The power grid of the future will likely include devices made from high-temperature superconducting (HTS) wires based on a technology developed jointly by ORNL and industry. Within the next two years American Superconductor Corporation plans to commercialize an HTS wire based on ORNL's RABiTS™ (rolling assisted, biaxially textured substrates) technology, which was licensed in 2000 to the Massachusetts-based company. The wire will be used to make cables that can help electric utilities deliver more power with greater voltage control and current density. Thus, RABiTS™ will help utilities meet increasing demands without building additional transmission towers or installing new underground rights-of-way under crowded city streets.

Ten years ago, ORNL developers of RABiTS™ demonstrated that crystallographic texture could be introduced into metal by rolling and annealing the metal into a thin tape, and that the texture can be transferred to a superconductive oxide coating through buffer layers deposited on the metal substrate. The buffer layers also block unwanted coating-substrate chemical reactions. The resulting orientation of crystals in the superconductive oxide, such as yttrium-barium-copper oxide (YBCO), allows the coated tape to conduct large electrical currents without resistance at liquid nitrogen temperature (77K).

American Superconductor is currently making a higher-performance, longer-length, RABiTS-based, nickel-tungsten substrate coated with very thin buffer layers. The company produces wide ribbons of material that will be slit into 100-meter-long, 4-millimeter-wide wires.

Today American Superconductor's first-generation, or 1G, HTS wires are commercial. Second-generation (2G) wires are expected to be a formed-fit replacement for 1G wires in the next few years. Researchers predict a decreased need for silver in the manufacturing process will make the 2G wire less expensive. Also, 2G wire will work better than 1G wire in the presence of a strong magnetic field in a motor, generator, or transformer.

In 2000 ORNL signed a cooperative research and development agreement (CRADA) with American Superconductor to develop the 2G wire using RABiTS technology, according to Bob Hawsey, manager of ORNL's Superconductivity Program. "We had a major achievement in 2004 in collaboration with American Superconductor," Hawsey says. "We developed a wet-chemistry method, called metal organic decomposition (MOD), for deposition of all layers on the nickel-tungsten alloy."

ORNL's Parans Paranthaman and University of Tennessee research professor Srivatson (Watson) Sathyamurthy, who developed MOD technology for the deposition of buffer layers, are working with American Superconductor to produce a 2G wire completely by wet chemistry processing. "A superconducting wire could be made like movie film, in which a plastic substrate is run through a series of chemical baths to place layers on the film," Hawsey says. "Currently, these layers are deposited on an ORNL substrate in a vacuum chamber, similar to the way semiconductors are made."

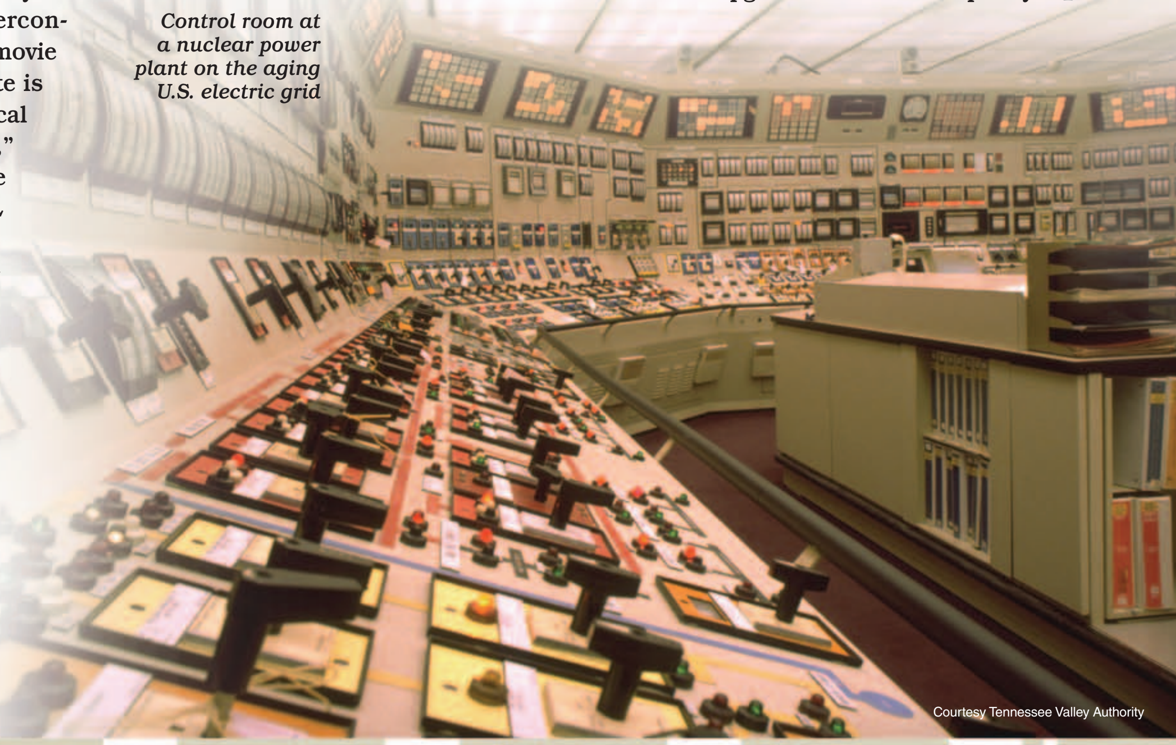
ORNL researchers produced a nickel-tungsten substrate on which they deposited a lanthanum zirconate buffer layer. ORNL sent the coated tape to American Superconductor, which deposited a cerium dioxide buffer layer on the tape plus a YBCO layer, using the company's proprietary process. The resulting wire carried 140 amperes of current in liquid nitrogen. By comparison, a copper wire containing much more material carries only 12 amps.

ORNL researchers continue to make progress in developing alternative approaches to growing YBCO on RABiTS substrates. For example, ORNL's Hans Christen and colleagues demonstrated in 2004 the viability of Neocera's pulsed- electron deposition system by achieving >1.5 million amperes/cm^2 on RABiTS samples. ORNL's Ron Feenstra and his collaborators showed that electron beam evaporation could be used to deposit YBCO on RABiTS and that short samples could carry about 400 amps of current, a 30% increase in current from 2003.

ORNL's largest and longest-running applied superconductivity project, which involves Southwire Company, is geared to developing and demonstrating superconducting cable technology. Southwire's 30-meter HTS cable with ORNL-designed terminations is operating five years after being energized in February 2000. ORNL and Southwire are making progress toward a 2006 demonstration of a 200-meter cable using 2G wire in Columbus, Ohio.

As utilities prepare to handle higher amounts of electric power in the future, they must upgrade their substations by replacing aging circuit breakers, which protect utility equipment from damage by shutting down the flow of electricity if, say, a tree falls across a transmission line and causes a short. Utilities could save money in the future by installing superconducting fault-current limiters instead of new, larger circuit breakers.

"We initiated a new CRADA with SuperPower on the development of fault-current-limiting technology that will operate at transmission level voltages of 138 kilovolts," Hawsey notes. "This technology would be a valuable new addition to electric utilities' toolkits for managing high fault currents as utilities upgrade substation capacity." ®



Control room at a nuclear power plant on the aging U.S. electric grid

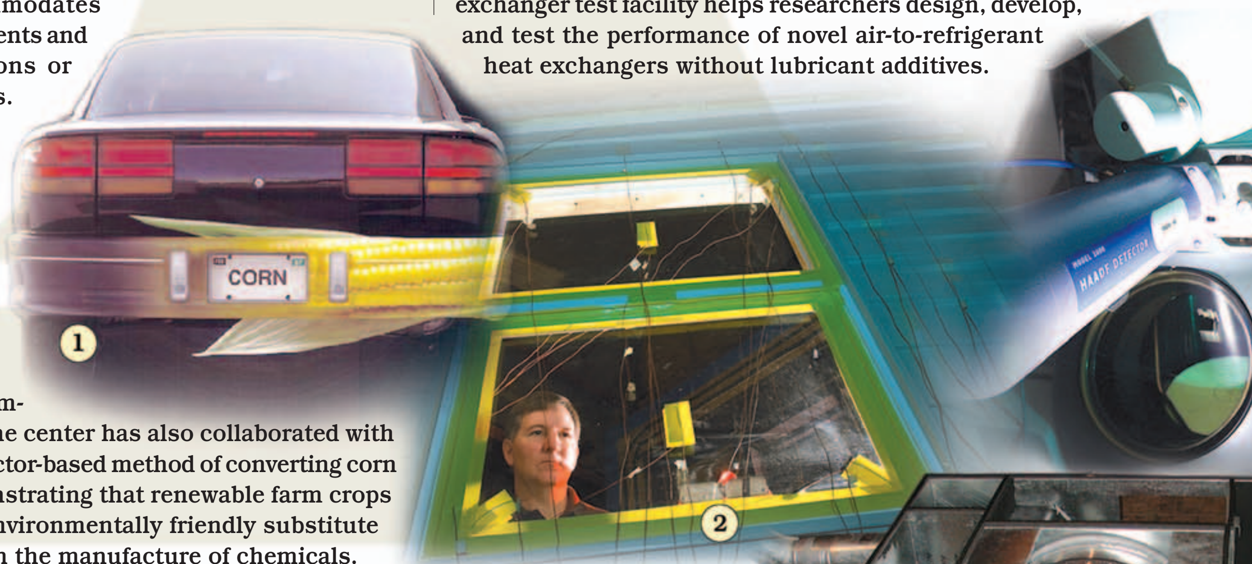
Courtesy Tennessee Valley Authority

Research Tools for the Nation

ORNL, industry, and university researchers collaborating at DOE national user facilities in Oak Ridge have helped improve nationwide energy efficiency.

State-of-the-art research equipment and tools that no industrial company or university can afford are available to researchers nationwide at the Department of Energy's national user facilities at ORNL. These facilities serve as catalysts for the development of partnerships and collaborations between ORNL and industrial or university researchers. Six of these facilities at the Laboratory receive funding from DOE's Assistant Secretary for Energy Efficiency and Renewable Energy (EERE). They are truly national resources for energy researchers.

The **Bioprocessing R&D Center** (1) houses equipment for the investigation of advanced bioprocessing concepts, including stirred-tank and columnar bioreactors and fermentation plant for large-scale batch and columnar experiments. The range of equipment sizes accommodates both bench-scale experiments and large-scale demonstrations or process scale-up studies. Researchers produced small, uniform, immobilized biocatalysts in the demonstration of a scaled-up fluidized bed for production of ethanol from corn. Ethanol is used as automotive fuel, helping reduce the nation's dependence on imported oil for gasoline. The center has also collaborated with others to develop a bioreactor-based method of converting corn into succinic acid, demonstrating that renewable farm crops can be a cost-effective, environmentally friendly substitute for imported petroleum in the manufacture of chemicals.



The **Buildings Technology Center** (2) is the premiere U.S. research facility devoted to the development of technologies that improve the energy efficiency and environmental compatibility of residential and commercial buildings. The BTC provides access to a unique collection of testing and analysis capabilities using state-of-the-art experimental equipment. Its mission is to help DOE, industry, and other customers identify issues and solve problems of major significance to building systems with solutions that are energy efficient, environmentally sound, and cost effective. The facility is composed of three centers: building envelope research, heating and cooling technology, and existing buildings research.

The centerpiece facility for building envelope research is the large-scale climate simulator, which sandwiches large roof sections between two environmental chambers. The upper climate chamber can simulate almost any outdoor weather condition, and the lower chamber typically models interior conditions. The rotatable guarded hot box is used to test full-size wall, window, roof, and floor systems; data from these tests have been entered into a whole-wall rating database. The roof thermal research apparatus has tested 24 different reflective roof coatings for low-slope roofs, to provide durability data for establishing the long-term thermal performance of the coatings. The envelope systems research apparatus is used to study energy and moisture flow through building envelopes. The complete apparatus tested simultaneously and defined the thermal performance of 40 different roof systems, accounting for changes in rooftop surface reflectivity over time. An indoor-outdoor environmental chamber simulates temperatures and humidity conditions for the development of cutting-edge air-conditioning, refrigeration, and heat pump technologies. A heat exchanger test facility helps researchers design, develop, and test the performance of novel air-to-refrigerant heat exchangers without lubricant additives.

The **Distributed Generation and Cooling, Heating, and Power (CHP) Integration Laboratory** (3) encourages the use of energy-efficient distributed energy generation systems, where users generate electricity on site using microturbines, turbines or reciprocating engines. Waste heat from these engines can be captured and used productively to increase system efficiencies to beyond 70% (approximately double that of conventional power plants).

This lab was one of the first facilities to test an integrated energy system (IES) for distributed generation (DG). Manufacturers could bring their equipment and evaluate its performance when coupled with any of the engines, heat exchangers, absorption chillers, or desiccant systems in the Lab. The manufacturers could also utilize ORNL-developed software to optimize the design and performance of advanced IES. New capabilities are being added to the laboratory to address the need for more efficient heat exchangers and chillers, and the challenge of generating and controlling reactive power from DG. Reactive power is increasing in importance and can be used to boost system efficiency, regulate voltage, and improve the power quality of the IES.

The **High Temperature Materials Laboratory** ④ is a specialized facility that houses a staff of materials experts and unique materials characterization equipment, including scanning transmission electron microscopes that can be operated remotely. HTML staff work with industrial researchers to solve materials problems that limit the efficiency and reliability of advanced energy conversion systems, such as gas-fired microturbines and reciprocating engines.

HTML's six user centers are devoted to materials analysis, mechanical characterization and analysis, diffraction, thermophysical properties, residual stress, and machining, inspection, and tribology. HTML staff have access to a new aberration-corrected electron microscope in ORNL's new advanced microscopy lab, enabling characterization of materials at the subatomic level.

Researchers at HTML are designing components for thermal management systems that will enable the efficient operation of fuel-cell–powered cars and many other devices where heat transfer is critical. These components are built by weaving graphite fibers with high thermal conductivity. The resulting structures possess thermal properties comparable to those of ORNL's revolutionary graphite foam, but they possess much higher damage tolerance and mechanical strength.

The **Metals Processing Laboratory Users Facility** ⑤ is designed to assist researchers in key U.S. industries, universities, and federal laboratories in improving energy efficiency and enhancing the competitiveness of the U.S. metals and materials industry in the global market. MPLUS provides access to the specialized technical expertise and equipment needed to solve metals processing issues that limit the development and implementation of emerging metals processing technologies. Here's an example:

When managers at the Logan Aluminum plant, which re-melts ingots of recycled aluminum-magnesium (Al-Mg) alloy to make Al-Mg alloy for can lids, learned about a problem, they came to MPLUS for help. The company found that a significant fraction of the alloy is very high in dross content, an aluminum oxide solid waste that is either sent to landfills or further processed to make Al-Mg alloy. Aluminum is produced from aluminum oxide using electricity, so dross formation represents a waste of energy for the aluminum industry. Logan Aluminum wanted to know why dross in ingots—originally formed when recycling companies melt aluminum alloy scrap and cast it into solid forms for transport to customers—is so high and how the dross is formed.

ORNL's Qingyou Han and his colleagues analyzed samples from the center of the ingots. When they heated the material to temperatures 200°C higher than the alloy's melting temperature, they found it did not melt but instead formed dross. Using a scanning electron microscope, they observed that a thin oxide layer surrounded aluminum grains, like an eggshell enveloping an egg.

"When the molten material is slowly cooled to form an ingot, air is pulled into the ingot's semi-solid center, leading to the formation of aluminum oxide on the surfaces of aluminum grains," Han says. "During re-melting of the ingot, the oxide layer does not melt. Instead, high-quality molten aluminum grains are entrapped in the oxide shell and turned into dross." Pete Angelini, MPLUS director, suggested a different way of cooling to minimize dross formation. The method has already been put to use by Logan Aluminum, reducing its energy use by an estimated 0.34 trillion Btu/yr.

The **National Transportation Research Center** ⑥ seeks to assist industry in using unique, state-of-the-art hardware and computing technologies to address problems of national and international significance, such as inefficient use of energy, dependence on foreign oil supplies, poor air quality, traffic congestion, and highway safety. The center has an array of unique testing equipment, including dynamometers to test diesel and other engines, as well as the Test Machine for Automotive Crashworthiness (TMAC), which measures the energy absorption properties of composites and metals when crushed in simulations of collisions between vehicles. NTRC houses centers and laboratories for the study of composite materials; fuels, engines, and emissions; photonics and remote sensing; and power electronics and electric machinery. ®

Energy Partners

ORNL's partnerships with industry, universities, and government agencies increase the probability that energy-efficient technologies will be adopted.

One mission of the Energy Efficiency and Renewable Energy (EERE) Program at ORNL is to conduct research that will lead to the development and commercial deployment of sustainable energy resources. Thus, the EERE program actively promotes partnerships and collaborations with industry, state and local governments, trade and policy associations, universities, and the Department of Energy and other federal agencies.

At the heart of this research and development activity is an enthusiastic commitment to finding ways to reduce the U.S economy's energy intensity. Involved partners are more likely to move technologies into the mainstream market. In addition, early collaboration can ensure that the unique issues of ORNL's customers are being addressed as the partners focus on more-energy-efficient practices

One hallmark of the EERE Program is effective partnerships across the five major technology sectors: buildings, distributed energy, industry, renewable energy, and transportation. Industrial partnerships are particularly integral to the success of the program, because they provide an important pathway to commercializing the results of R&D activities. Other articles in this issue of the *ORNL Review* provide numerous examples of these industry collaborations.

Two additional key partnerships are featured in this article: the program's growing relationship with the Tennessee Valley Authority (TVA) and partnerships with various energy offices of the states.

Emissions and fuel use during truck idling are being studied by ORNL, UT, and New Jersey researchers.

TVA—Critical Regional Partner

In the past few years, TVA, as America's largest power producer, and ORNL, as the largest energy laboratory, have led the nation in advancing energy efficiency and energy security. Major activities in which ORNL and TVA have collaborated include:

- Invention of the frostless heat pump by ORNL researchers in response to TVA's request for an electric appliance that would be competitive with gas units by providing greater thermal comfort, while increasing energy efficiency by minimizing the heat pump's defrost cycle
- Promotion of heat pump water heater technology, which is 50% more energy efficient than traditional water heaters, with the leading water heater manufacturers
- Field testing hybrid solar lighting technology, which has resulted in the creation of a more marketable third-generation technology
- Participation in the design and construction of near-zero-energy prototype Habitat for Humanity houses
- Pursuit of the effective integration of photovoltaics into roofing structures
- Development of low-cost sensor detection approaches to monitoring power transmission performance
- Investment in a range of power transmission research projects, such as testing advanced conductors, at DOE's National Transmission Technology Research Center at ORNL
- Support of a regional networking infrastructure to more effectively link the computers of ORNL and the region with computers at other national research centers
- Participation of ORNL as the first major industrial customer of TVA's "green power" program.

ORNL and TVA continue to assess areas of mutual interest in developing technologies and capabilities that are national models for advancing energy efficiency, security, and economic development.

State Partnerships

Three different initiatives with states have provided effective approaches to accelerating the development and deployment of sustainable energy technologies throughout the country:

The **State Partnerships Program,** which was initiated in 1996, awards ORNL research and technical assistance support to states in response to solicitations for projects. The principal partners targeted through this process are the National Association of State Energy Officials and the Association of State Energy Research and Technology Transfer Institutions. Since the program's inception, the EERE Program has completed projects with energy offices in 36 of the 50 states. For example:

- ORNL researchers analyzed the potential for energy efficiency in Iowa and determined that state funding would have the greatest impact through a combination of market-based programs and standards that target both the residential and commercial sectors.
- Researchers with the National Transportation Research Center of ORNL and the University of Tennessee, the U.S. Environmental Protection Agency, and New Jersey are cooperating to measure and characterize emissions and fuel use during idling of long-haul trucks to help state energy and air quality offices do their planning and to support development of technologies that mitigate emissions and reduce fuel waste.
- Seattle, Washington, has been plagued by failures of recently constructed buildings resulting from damage induced by moisture. The city and Washington State University have partnered with ORNL to determine the cause of the premature deterioration of these buildings and to develop building envelope designs and control strategies that achieve both energy efficiency and moisture control.

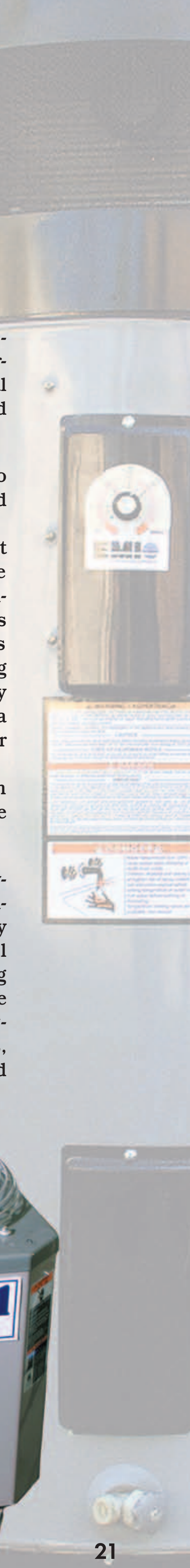
The **Technical Assistance Project** provides assistance to states through a collaborative effort among three DOE national labs—ORNL, National Renewable Energy Laboratory in Colorado, and Lawrence Berkeley National Laboratory in California. The project supports short-term technical assistance for initiatives involving system benefits charges or other rate-payer–funded utility efficiency and renewable programs, renewable or efficiency portfolio standards, use of clean energy technologies to help states and localities address air emissions, or use of renewable energy on both state and local public lands. Examples of recent projects supported through ORNL include:

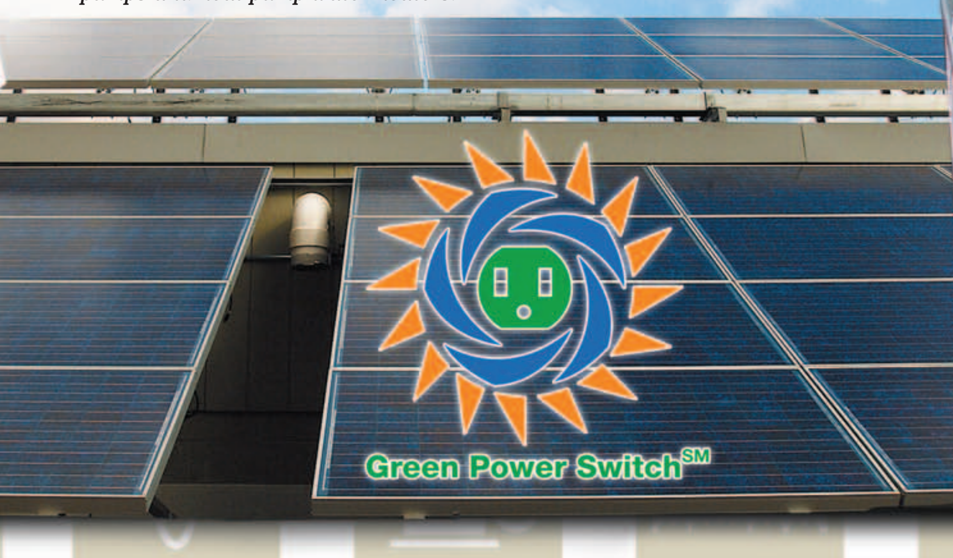
- Development of emissions metrics (undesirable and desirable levels of airborne nitrogen oxides, sulfur oxides, carbon dioxide, volatile organic compounds, and particulate matter) associated with state implementation plans for air quality improvement in Tennessee
- Recommendations for developing an energy efficiency technology portfolio standard for New Jersey
- Assessment of the soil composition of state land for growing biomass fuel material in Florida

In a third initiative, the EERE Program is collaborating with the **Education and Research Consortium of the Western Carolinas (ERCWC)** in transferring technology in the rural Western Carolinas. The goal is to translate energy-efficient technology concepts into marketable products that have significant potential for reducing both energy use and energy costs, as well as support economic development and education in the region. Five projects currently under way involve ERCWC and other regional university, community college, institutional, and industrial partners. These projects include:

- Development of climate-based software tools to support EERE applications for local, state, and regional use
- Manufacture and testing of an energy-efficient dual-service water heating appliance prototype
- Creation of a Western Carolina Office of Technology Transfer, supported by EERE technologies transferred from ORNL and other organizations
- Provision of community college campus building and industrial assessments for energy efficiency opportunities to support the development of a Western Carolina industrial assessment center at a community college
- Creation of a user-friendly exhibit in North Carolina's new Arboretum facility to educate the public about energy-efficient practices

The ORNL-EERE Program's success at achieving energy sustainability and security for the nation rests upon maintaining and developing fully engaged partnerships and collaborations with all major players in the marketplace. Establishing effective and ongoing relationships with multiple partners helps ensure the adoption of energy-efficient technologies throughout the buildings, distributed energy, industry, renewable energy, and transportation market sectors. Ⓡ





Projects involving TVA and ORNL include (left to right) integrating photovoltaics in roofs, purchasing of TVA's "green power" by ORNL, and promoting frostless heat pumps and heat pump water heaters.

PROFILE

JOHN PETERSEN:
Focusing on the UT-ORNL Synergy

On July 1, 2004, Dr. John Petersen became the University of Tennessee's 23rd president. By virtue of this role, he also chairs the board of directors for UT-Battelle, the partnership that manages ORNL for the Department of Energy. The university and the laboratory share a rich, 60-year history of teamwork and joint initiatives. Petersen recognized and embraced this synergy and last June made it the focus of his very first public address to the region. A chemist whose research was funded by the Department of Energy, Petersen is familiar with the national laboratory system and has an unabashed enthusiasm for UT-ORNL joint research. The growing research portfolio includes the Science Alliance, with divisions in biological, chemical, physical, and mathematical-computer science; and joint institutes and centers in heavy ion research, computational sciences, neutron sciences, energy and environmental research, biological sciences, transportation research, and environmental biotechnology.

Before coming to UT, Petersen served as provost and executive vice president at the University of Connecticut; dean of the College of Science and professor of chemistry at Wayne State University; head of the chemistry department and associate dean for research in the College of Sciences at Clemson University; and assistant professor of chemistry at Kansas State University.

Q. You took office July 1, but your first public address in Tennessee was June 2 at the Tennessee Valley Corridor Summit in Oak Ridge. How did it come about that your Tennessee debut was in Oak Ridge?

Once I accepted the UT president's position in April, the Tennessee Valley Corridor Summit invited me to come and talk in the opening round in Oak Ridge. So I came here for the luncheon with Homeland Security Secretary Tom Ridge and then gave the talk. Typically, I would not have made such a visit before I had taken office to talk about the university because I really wasn't an employee of the institution at that time. But to me, the partnership that UT has with the lab and the value of what that can bring in terms of technology development in this region were worth coming down and talking about. Obviously, a lot of the details about the university were not at my fingertips then, but I got a chance to discuss my philosophy on how universities and national laboratories can relate in what they do. I enjoyed doing that and was happy to accept that invitation.

Q. How have your experience with the Department of Energy and your research background in inorganic chemistry shaped your insight into the UT-ORNL relationship?

I spent 15 years, from 1980 to 1995, in the Department of Energy's Solar Photochemistry Program, working with researchers from Brookhaven, Argonne, Berkeley, Livermore, Los Alamos and Oak Ridge national labs. Meeting and working with these people, I became fairly familiar with national labs and how they work. As a chemist in general, I understand the science, but as a chemist who was funded in this program for so long, I also came to better understand the national labs, the type of research they do, their strengths and weaknesses. The experience also helped me recognize the complementary nature of a university-national laboratory partnership. In the past, universities generally have been richer in personnel and faculty than in facilities and equipment, with the opposite situation being true for national labs. When you can run a match that really works, especially in the areas we are looking to mesh in terms of the UT-ORNL joint institutes, the partnership can be an enormous advantage.

Q. What are your thoughts on the state's $26 million commitment to research in neutron sciences, nano-science, biology, and computer sciences in support of UT-Battelle's management of ORNL?

I think the state's commitment to the management team certainly is unique. Most of the national lab organizations I'd been involved with were usually run by different types of enterprises, but partnerships like Battelle and the University of Tennessee now are becoming the wave of

how national labs are managed, and there are a number of advantages to that. UT had a relationship with ORNL far preceding the management contract change, but to be actively involved in the management of the lab really creates an opportunity to bring the university and the lab a lot closer. Being able to sit as partners and strategically plan how we mutually work together on such things as jointly hiring faculty and other issues is going to be very important in terms of projecting ORNL as the top national lab in the country and UT and Battelle as viable partners in that enterprise.

Q. ***On November 9, at your first major policy address to the UT Board of Trustees, you announced plans for increased emphasis on UT system and ORNL collaborations in computational sciences, biology, nanomaterials, and neutron sciences. What are your observations on these joint initiatives and the lab's "nano-info-bio" thrust?***

These institutes focus on areas in which we feel both the university and the lab can be national and international leaders. Working with ORNL and supplementing ORNL funds with state dollars, we can hire the best people in the world in those areas. These areas are multidisciplinary and can prove to be a broadening area for other disciplines. If you take nanotechnology and combine it with biology and computational sciences, what you find are three fields that are coalescing into the single hottest field in the next few decades. There are similar corridors being built in Silicon Valley, Texas, and other places, but we are going to bring other pieces to bear that will reinforce nanotechnology in East Tennessee.

Q. ***Given the plans for future joint institutes and other upcoming major projects, one of ORNL's top challenges in the immediate future is recruiting world-class talent to do the research. What role does the university play in helping ORNL meet the incredible demand the lab faces for recruiting scientists over the next 10 to 20 years?***

The UT-ORNL relationship is an enormous recruitment advantage for attracting top-flight people who want to work in a university setting but who also want to be able to do their science in first-rate facilities with excellent support. Our partnership enables us to give them both. As institutions get better—which we obviously plan to do at the University of Tennessee—they typically improve incrementally. You hope that you can hire faculty members that are a little better than you are and continue to ramp up, because it is difficult to make a quantum jump in terms of faculty. But I think the key to this relationship is the presence, equipment, support, and all that a national lab brings to a UT faculty position, as well as what being associated with a university means to people who are interested in working at ORNL. This unique partnership affords us the opportunity to make a fairly good quantum leap in terms of the quality of the faculty we hire. So, if we can go out and target some key, high-profile individuals in these areas in which we have decided to work together, the result will raise the reputation of both the lab and the university, and will also help us pursue the other recruiting we need to really build some world-class programs.

Q. ***What are your long-term goals for the ORNL-UT partnership?***

I want us to continue to expand in the four joint research areas we are developing. We could easily see an aggressive five- to ten-year agenda in terms of building faculty in those areas, enhancing the relationship, and looking at these joint appointments. Another goal is to build on UT-Battelle's success in bringing intellectual property into the marketplace, which has resulted in 43 new businesses since 2000. I see the partnership continuing to evolve, spinning out technologies we generate and helping them work for the state in the form of new companies and jobs. As we prove the success of that model, we can look down the road at other ways that we might intersect to help enhance East Tennessee and make the region a real draw for people in those areas on which we choose to focus. Of course, my main goal is to continue to build and strengthen the relative position of this institution, regionally and nationally. My interest is in the University of Tennessee, what it can do for the state and its people, and how good we can make it. Having a partner such as Oak Ridge National Laboratory involved certainly helps facilitate that. Ⓡ

Courtesy University of Tennessee

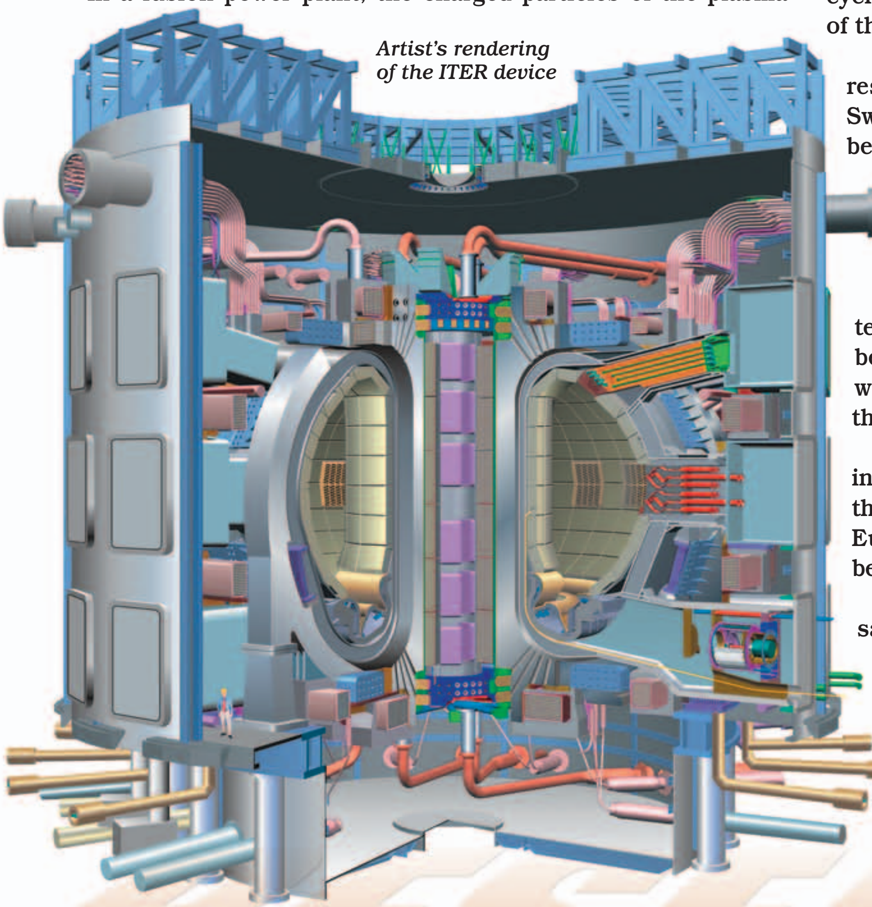
FUSION: A Big Win for ORNL

ORNL's selection as a U.S. project manager for ITER means the Laboratory's multi-pronged fusion research will likely influence the international fusion reactor's design and research program.

U.S. participation in designing and operating an international fusion reactor is the top priority in the Department of Energy's 20-year plan for scientific research facilities. So it was not surprising that ORNL staff were elated by a major announcement in July 2004 by Ray Orbach, director of DOE's Office of Science. Orbach said that ORNL, in partnership with the Princeton Plasma Physics Laboratory, will lead the U.S. contribution to the International Thermonuclear Experimental Reactor project. Construction of ITER, a $5 billion international fusion experiment, is scheduled to begin in 2006 with initial operations in 2013.

The U.S. project office for ITER will be hosted by PPPL, located in New Jersey. The Princeton-ORNL team will oversee the office, provide staff and facilities, and support construction of ITER at a site in either France or Japan. ORNL has traditionally been a partner on fusion-related projects with PPPL, a national collaborative center for plasma and fusion science.

The potential of fusion energy is extraordinary in the context of the world's energy and environmental challenges. A fusion power plant would produce no greenhouse gas emissions, use widely available fuel, require no fissionable materials, produce heat continuously to meet demand for electricity, shut down easily, and produce manageable radioactive waste. In a fusion power plant, the charged particles of the plasma fuel—heavy hydrogen nuclei such as deuterium extracted from seawater and tritium bred in the reactor—would be heated to 100 million degrees and held close together by magnetic fields for a sufficient time for heat-producing fusion reactions to occur. The heat would make steam to produce electricity.



Artist's rendering of the ITER device

Heating and Fueling the Plasma

Because of ORNL's outstanding research contributions to fusion physics and technology since the 1970s, DOE has selected the Laboratory to play an important role in the international fusion project. ORNL will be involved in designing and building systems for heating and refueling ITER's plasma.

"Our approach to ITER is to provide an integrated package of research and development to maximize the impact of our contribution," says Stan Milora, director of ORNL's Fusion Energy Division. "As such we have targeted key plasma control technologies for heating, fueling, and diagnosing the plasma, and we will complement these contributions with theory and simulation, technology developments, and experiments on existing fusion facilities."

ORNL's David Swain, who works part-time for the ITER International Team, is responsible for development of ITER's ion cyclotron heating (ICH) system. ICH will boost the temperature of the ITER plasma.

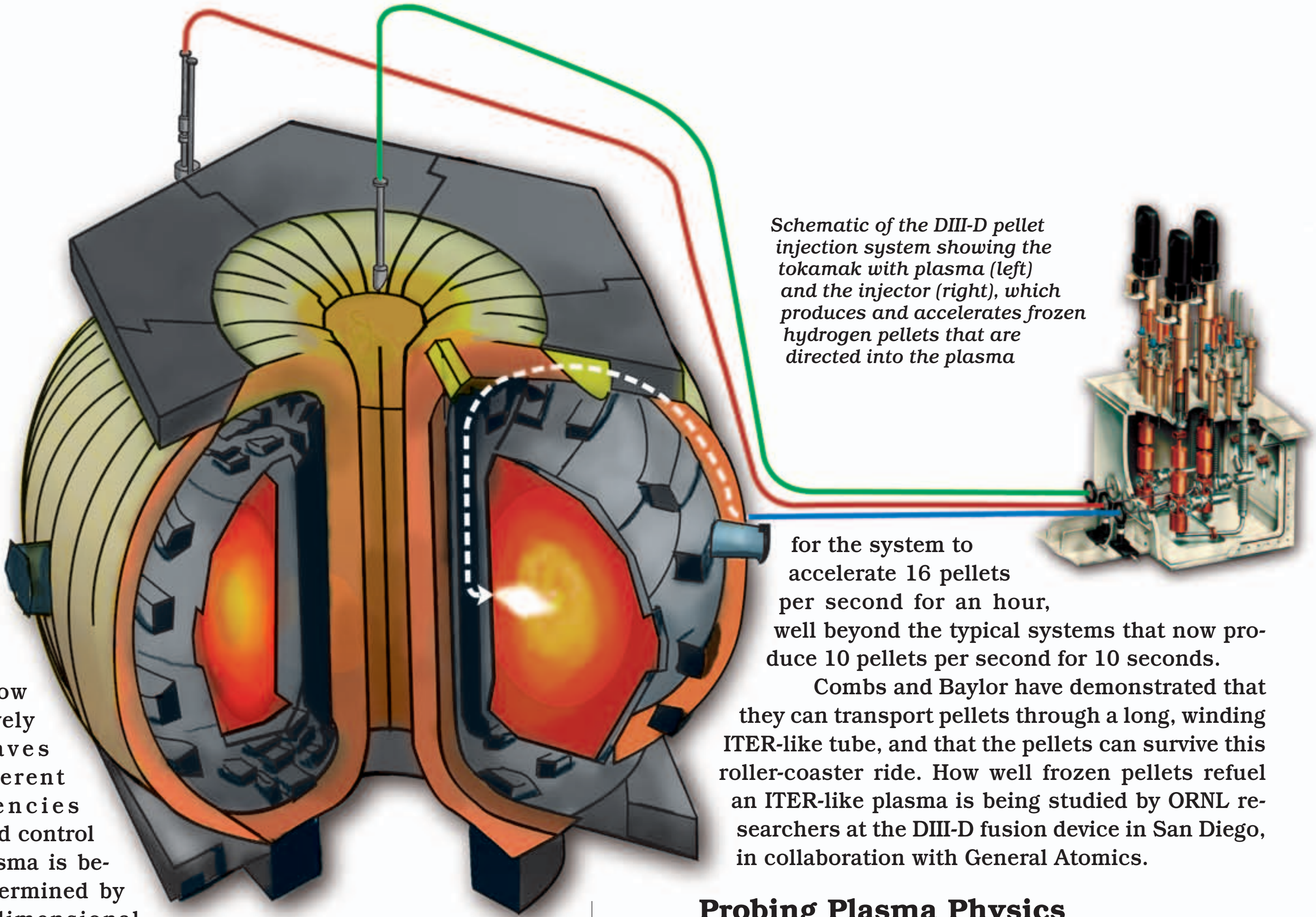
"My job involves leading a team of U.S. and European researchers to design, build, and assemble an ICH system," Swain says. "ORNL researchers, led by Dave Rasmussen, have been doing most of the U.S. research and development on the antenna, the critical component of the ICH system and its biggest technical challenge."

The antenna will deliver 20 million watts of high-frequency radio waves to the ions in the plasma, causing the plasma to heat up. One ORNL improvement in the antenna is the location of capacitors right behind the antenna's beryllium surface at the vessel's inner wall. The capacitors would be used to tune the radiofrequency waves, enabling the waves to control, as well as heat, the plasma.

Rick Goulding and other members of Rasmussen's group, in another partnership with PPPL, are developing a prototype of the ICH antenna that will be installed and tested on the Joint European Torus (JET) in England. A one-strap prototype has been built and tested at ORNL in vacuum at high voltage.

"We saw some problems in the original design," Swain says. "We found hot spots in the antenna, so we modified the design and plan to test it again in February 2005. If successful, the Europeans will then build a four-strap antenna. ORNL will work with them on its final design and operation at JET, probably in 2006. If this ICH design works well, then it should be a strong contender as the plasma heating system concept for ITER."

RESEARCH



Schematic of the DIII-D pellet injection system showing the tokamak with plasma (left) and the injector (right), which produces and accelerates frozen hydrogen pellets that are directed into the plasma

How effectively RF waves of different frequencies heat and control the plasma is being determined by three-dimensional models run on a supercomputer at ORNL. Don Batchelor, theory group leader, is leading this effort as part of a Scientific Discovery through Advanced Computing (SciDAC) project in collaboration with PPPL, the Massachusetts Institute of Technology Plasma Science and Fusion Center, and three small businesses.

A team led by ORNL Corporate Fellow Steve Zinkle is studying how well the materials in the ICH antenna, high heat flux regions of the vessel, tritium test breeding modules, and plasma diagnostics will hold up under neutron irradiation and other stresses.

Pellet fueling, pioneered at ORNL by Stan Milora and Chris Foster in the late 1970s and further developed by Steve Combs and Larry Baylor, has been used successfully to refuel the plasmas of fusion research devices in England, France, Germany, and Japan. The pellets of frozen deuterium at a temperature of about 10 degrees Celsius above absolute zero must be accelerated to high speeds to penetrate to the hot fusion plasma. Milora and Combs developed a gas-powered pellet injection gun used in U.S. and European fusion experiments, and Foster invented a centrifugal-type mechanical arm to fling pellets into the plasma. This technology, employed in Europe and Japan, likely will be used on ITER.

The challenge for ORNL researchers is to build a device that produces frozen deuterium and tritium pellets, the size of pills, and injects them into ITER's plasma at 300 meters per second, a speed equivalent to that of a Boeing 747 jet at altitude. The pellet system must produce 10 times more deuterium ice than is made at fusion devices today. ITER requirements call for the system to accelerate 16 pellets per second for an hour, well beyond the typical systems that now produce 10 pellets per second for 10 seconds.

Combs and Baylor have demonstrated that they can transport pellets through a long, winding ITER-like tube, and that the pellets can survive this roller-coaster ride. How well frozen pellets refuel an ITER-like plasma is being studied by ORNL researchers at the DIII-D fusion device in San Diego, in collaboration with General Atomics.

Probing Plasma Physics

ORNL researchers are engaged in a wide range of physics research activities that contribute to the ITER program. At DIII-D Mickey Wade and Masanori Murakami are leading a study on the hybrid scenario for operating ITER to achieve high fusion output. In this scenario a current generated by the plasma itself minimizes the need for a transformer, making the fusion power plant more attractive to electric utilities.

Donald Hillis is involved in developing a key diagnostic tool for JET that is a strong contender for use on ITER. JET is the only tokamak capable of producing an ITER-like, deuterium-tritium (D-T) plasma and the helium "ash" resulting from fusion reactions. In future burning fusion devices, spectrometers will continuously monitor helium ash as it is produced and removed from the plasma core to prevent D-T fuel dilution and quenching of the burn.

Hillis has fabricated two high-efficiency spectrometers for measuring the helium ash concentration produced in JET. He also uses spectroscopy to measure variations in the intensity of the light emitted from JET's plasma to determine its ion temperature and ion flow velocities, key indicators of fusion device operation.

This wide spectrum of capabilities contributes to making ORNL a leader in fusion research. "Our goal at ORNL is to have a lead role in ITER's experimental program, and that's why we are seeking to support the ITER project in these critical areas," Baylor says. "In that way, ORNL would be a key player in demonstrating to the world the feasibility of fusion as part of a long-term answer to our energy needs." Ⓡ

Attractive Materials Process

Use of a magnetic field can increase the strength and fracture resistance of steel and other ferromagnetic alloys.

ORNL researchers have discovered that applying a magnetic field to steel and other ferromagnetic materials could dramatically improve their strength, wear resistance, and lifetime and make the materials easier to shape into parts, using less energy than conventional methods. Their initial research results are attracting the attention of industry, including manufacturers of steel, superconducting magnets, automotive parts, and knee and hip implants.

The promising discovery occurred in ORNL's Metals and Ceramics (M&C) Division and in experiments at the National High Magnetic Field Laboratory at Florida State University. The insight comes at an opportune time for the U.S. steel industry because magnet companies now manufacture cost-effective superconducting magnets that generate increasingly stronger magnetic fields with low consumption of energy.

"This finding could revolutionize materials processing as it provides a new approach to developing novel materials with enhanced performance that would be unachievable through other processing avenues," says Gerard M. Ludtka, a materials scientist in ORNL's M&C Division who is leading this investigation. "The steel, heat treating, forging, welding, casting, chemical, and cast iron industries can benefit from research on materials processing using powerful magnets."

Steel and other ferromagnetic materials are usually modified so they can be more easily shaped into long-lasting components by changing their recipe—the ingredients in their chemical composition, the temperature to which they are heated, and the speed at which they are cooled. Turning a magnetic field on and off could dramatically strengthen a material by, for example, increasing the solubility of desired alloy additions to form a microstructure never seen before, possibly generating improved properties. Changing a material can be accomplished using magnetic processing because this method has been shown to alter the fundamental phase stability and microstructure evolution kinetics exhibited by ferromagnetic materials.

"A magnetic field can influence the energy levels of electrons within an atom, affecting the chemical bonding and crystal structure and behavior of the material," Ludtka says.

Ludtka found that magnetic fields can soften steel, making it easier to machine the material to form desired component shapes. "After a steel part is machined, the usual heat treatment can be given to the material so the desired properties return," he says.

In a seed-money project, Ludtka in 2000 demonstrated that residual stresses in a steel sample at room temperature can be reduced 80% by exposing the steel to a low magnetic field with strengths ranging from 1 to 6 Teslas. Residual stresses can lead to cracks, fracture, and failure of the material during exposure to altered temperatures or applied stress.

"We envision using magnetic fields from a 2-Tesla magnet, like the magnet in an MRI medical imaging device, to treat steel components of a diesel engine that has operated a long time," he says. "These parts develop residual stresses over the life of the engine because of cyclic exposure to hot and cold temperatures. We would zap each component with a magnetic field and, based on literature results, conceivably increase life expectancy by 30%."

In a 2001 project supported by internal funding from ORNL's Laboratory Directed Research and Development Program, Ludtka and his colleagues—Roger Kisner, Gail Mackiewicz Ludtka, John Wilgen, Roger Jaramillo, and Don Nicholson—showed they could double the desired mechanical properties of certain microstructures using magnetic field processing.

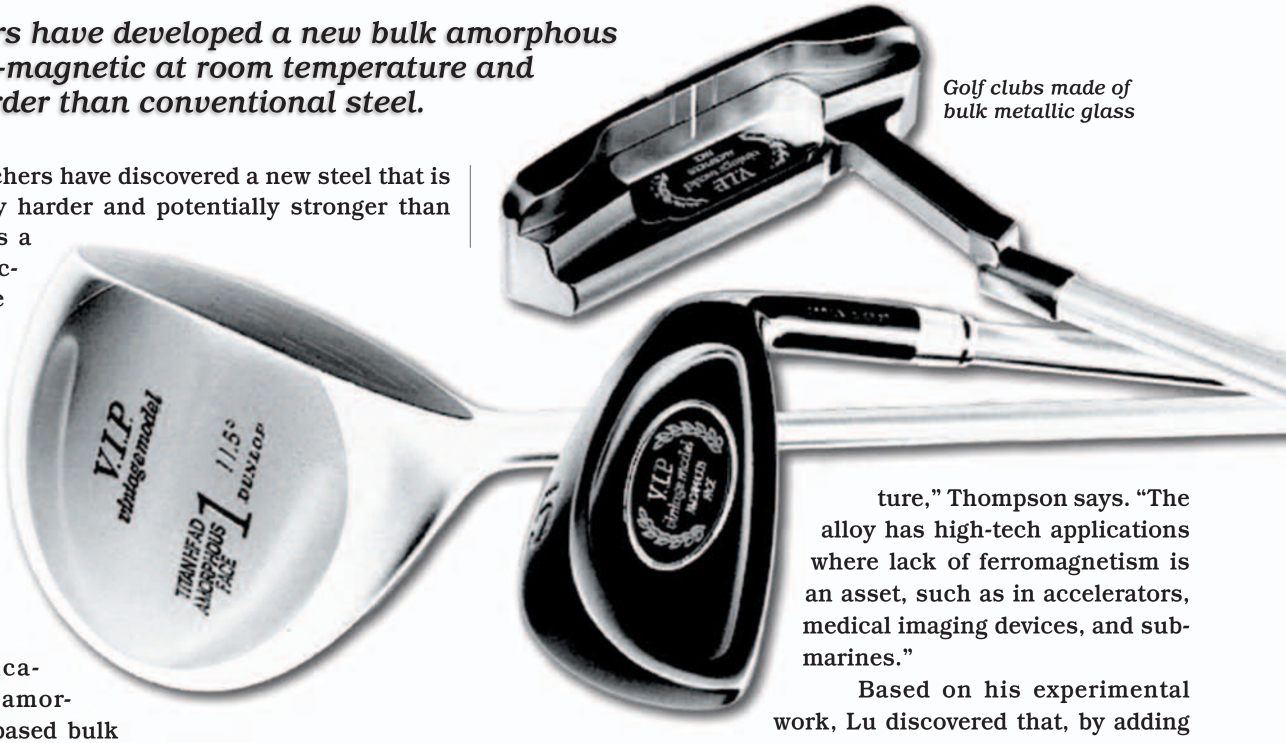
Magnetic field processing might lead to high-strength steel so strong that the thinnest of sheets would form the body of a car, greatly reducing weight and increasing efficiency, Ludtka says. The technique might even produce a "dream steel" for national security—a structural alloy for skyscrapers that becomes stronger and more resistant to catastrophic failure under the heat after an impact, such as being struck by an airplane.

Magnetic processing could be used by the orthopedic implant industry to make improved artificial knees and hips. "By stabilizing more of the preferred hexagonal phase microstructure, magnetic fields could confer increased wear resistance and longevity on cobalt alloy implants," says Ludtka, who received the Department of Energy's E. O. Lawrence Award in 1994. Ⓡ

RESEARCH

Glassy Steel

ORNL researchers have developed a new bulk amorphous steel that is non-magnetic at room temperature and significantly harder than conventional steel.



Golf clubs made of bulk metallic glass

ORNL researchers have discovered a new steel that is significantly harder and potentially stronger than ordinary steel yet has a jumbled atomic structure like glass. The glassy steel, which has been described in *Physical Review Letters* and *Nature*, also may have better magnetic properties and corrosion resistance than industrial steel, which has an orderly crystalline structure.

Possible applications for this bulk amorphous steel, or iron-based bulk metallic glass, could include tougher medical implants, lighter aircraft, die tools, tennis rackets, and golf clubs. The properties of bulk metallic glasses—alloys whose atoms are almost randomly arranged—are usually superior to those of counterpart materials whose atoms are arranged in repeating patterns typical of crystals.

Recent advances at ORNL in projects initially supported in 1996-97 by the internally funded Laboratory Directed Research and Development (LDRD) Program and later by the Department of Energy, as well as work in other laboratories throughout the world, have stimulated efforts to fabricate bulk amorphous steels. The LDRD project led by ORNL Corporate Fellow C. T. Liu produced an unusually thick zirconium-based bulk metallic glass.

Liu and Zhao Ping Lu, both of ORNL's Metals and Ceramics (M&C) Division, sought to make a bulk amorphous steel using ordinary industrial processes and alloying materials. Such a material would be much cheaper than zirconium-based bulk metallic glasses and would theoretically possess greater strength, hardness, and corrosion resistance than conventional steel.

The discovery of the unique steel was reported in *Physical Review Letters* by Lu and Liu, who heads the Alloying Behavior and Design Group in the M&C Division; Wallace Porter of M&C's Diffraction and Thermophysical Properties Group, and James R. Thompson, who holds a joint position in ORNL's Condensed Matter Sciences Division and the University of Tennessee's Physics Department.

Nanoindentation tests by Hongbin Bei, a UT postdoctoral researcher, revealed that the new steel is 3 to 4 times harder than ordinary steel, suggesting it is stronger. "The ORNL steel, unlike conventional steel, is not magnetic at room temperature," Thompson says. "The alloy has high-tech applications where lack of ferromagnetism is an asset, such as in accelerators, medical imaging devices, and submarines."

Based on his experimental work, Lu discovered that, by adding yttrium to a molten material that is 44 atomic percent iron and contains smaller percentages of boron, carbon, chromium, cobalt, molybdenum, and manganese, the material could be cooled so as to freeze into a noncrystalline instead of a crystalline structure. The stumbling block to producing a practical bulk amorphous steel has been the great difficulty in achieving the low critical cooling rate, or large glass-forming ability, of any iron-based alloys.

The addition of yttrium enabled the alloy to remain in a "liquid-like" structure at very low temperatures and thus stay amorphous as it solidified. Also, yttrium retarded the growth of iron carbide crystals, making the steel less likely to become crystalline.

Gravity enabled the molten iron liquid to drop cast into a copper mold, producing a bulk amorphous steel rod with a diameter of 12 millimeters (mm), 3 times the thickness of previously fabricated bulk amorphous steel rods containing no yttrium additions. The ORNL rod's glasslike structure was verified using X-ray diffraction and optical microscopy.

The research was sponsored by a private company, DOE's Division of Materials Sciences and Engineering, Office of Basic Energy Sciences, and DOE's Assistant Secretary for Energy Efficiency and Renewable Energy, Office of FreedomCAR and Vehicle Technology Program as part of the HTML User Program.

A group at the University of Virginia also produced a 12-mm rod made of a bulk amorphous steel of a different composition. Liu says that the challenge is to learn how to easily make bulk amorphous steel as thick as 20 to 30 mm.

A reviewer of the ORNL paper says that fabrication of a thicker bulk metallic glass of structural steel is "an extremely important discovery that should have a large impact on society." Ⓡ

...and the WINNERS are...

Accomplishments of Distinction at Oak Ridge National Laboratory

C. T. Liu received the ***ORNL Director's Award for Outstanding Individual Accomplishment in Science and Technology*** and the ***Distinguished Scientist Award*** at the UT-Battelle 2004 Awards Night ceremony for his research on advanced materials, both in increasing fundamental understanding of their mechanical properties and in their application to energy systems.

Four ORNL technologies received national ***Federal Laboratory Consortium Excellence in Technology Transfer Awards***: MicroCAT X-ray technology (top project in Southeast FLC competition), developed by **Shaun Gleason, Michael Paulus, Derek Austin, Miljko Bobrek, Gary Alley, Kenneth Tobin,** and **Chris McKinney**; AquaSentinel real-time water monitoring biosensor system, developed by **Elias Greenbaum, Miguel Rodriguez, Charlene Sanders, David Hill, Richard Stouder, Mark Reeves,** and **John Harrell**; the photo-molecular comb biomolecular separator, developed by **Thomas Thundat, Gilbert Brown, Thomas Ferrell, Robert Warmack**, and **Russ Miller**; and the miniature californium-252 neutron source for cancer therapy, developed by **Rodger Martin, Ian Gross, Larry Pierce, Russ Miller, Mark Reeves**, and **Manfred Sandle**r. These technologies all placed in the Southeast FLC competition, along with ORNL's MicroTrap MS™ Microscale Ion Trap Mass Spectrometer, developed by **Bill Whitten, Peter Reilly, Mike Ramsey**, and **Ashok Choudhury**.

James B. Roberto has received the ***National Materials Advancement Award*** from the Federation of Materials Societies for a number of materials sciences-related activities both nationally and at ORNL, including managing one of the nation's largest materials science and engineering programs.

C. T. Liu (left) and ORNL Director Jeffrey Wadsworth.

Thomas Thundat has been named one of the "***Scientific American 50 Award***" winners for his development of devices that use microcantilevers to detect TNT. **Thundat** also received the ***Jesse W. Beams Award*** for research excellence from the Southeastern Section of the ***American Physical Society***.

Everett Bloom has received the ***Outstanding Achievement Award*** from the Materials Science and Technology Division of the ***American Nuclear Society***, in recognition of his "significant and sustained contributions to the development of materials for advanced nuclear fission and fusion systems."

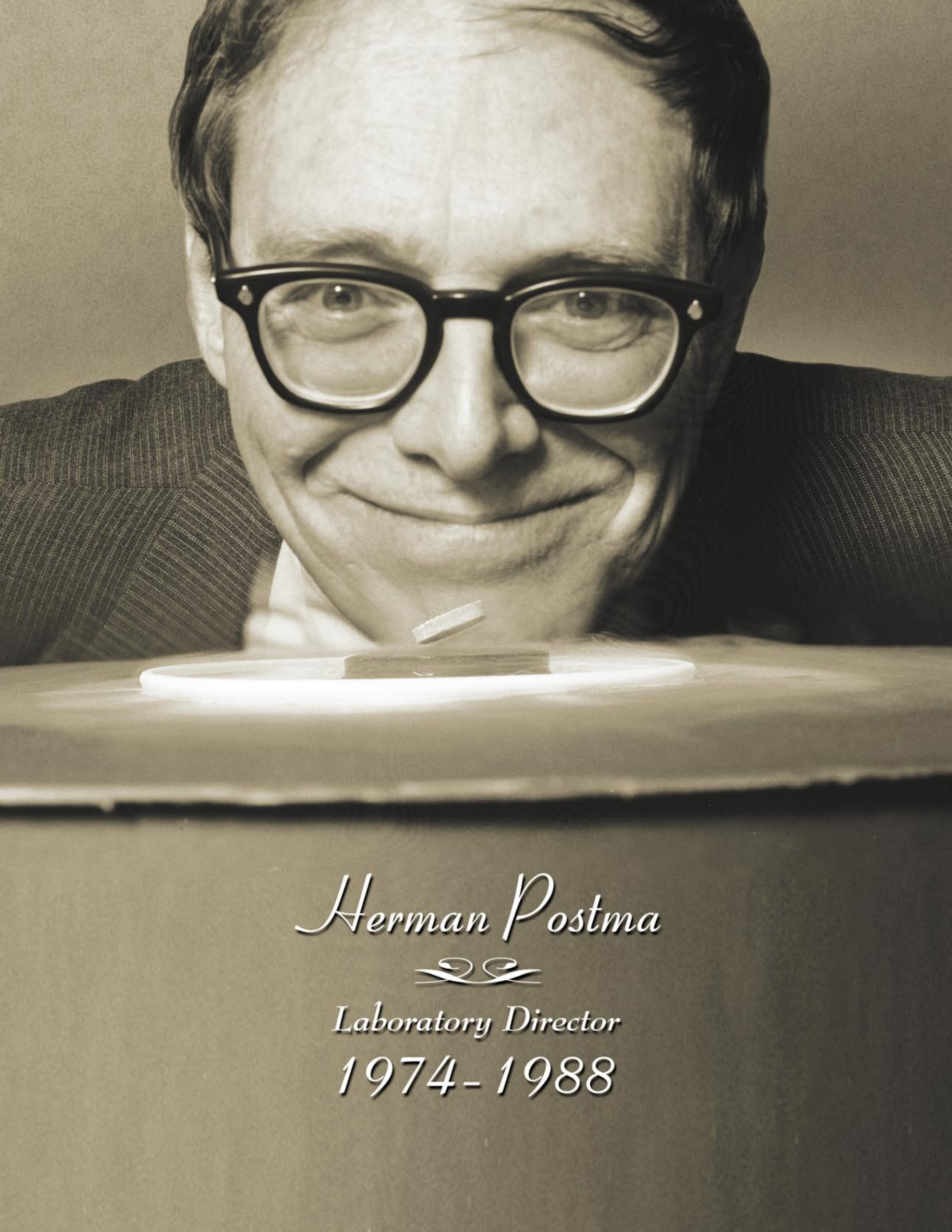
Lætitia Delmau has been named by MIT's *Technology Review* magazine as one of the ***world's top 100 young innovators*** for her development of patented technologies for treating nuclear wastes.

Johney Boyd Green, Jr., has been recognized by *Science Spectrum* magazine as ***one of the 50 most important black research scientists*** in America for his contributions to automotive research and for his service as a role model to students.

Kelly Beierschmitt is a member of the Battelle group that received the ***White House "Closing the Circle" Award*** for ORNL's "green building" designs for the new east campus.

Stephen Pennycook, Amit Goyal, Robert Cushman (retired), and **Leonard Feldman** have been elected ***fellows of the American Association for the Advancement of Science***.

David Dean, Tony Mezzacappa, Predrag S. Krstic, and **Lal A. Pinnaduwage** have been elected ***fellows of the American Physical Society***.®


Herman Postma
Laboratory Director
1974-1988

OAK RIDGE NATIONAL LABORATORY *REVIEW*
P.O. Box 2008, Oak Ridge, Tennessee 37831-6266

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Editorial office telephone: (865) 574-7183;
Editorial office FAX: (865) 241-9787;
Electronic mail: krausech@ornl.gov
Web addresses: www.ornl.gov
www.ornl.gov/ORNLReview/

The *Review* is printed in the United States of America and is also available from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161

Oak Ridge National Laboratory is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725

ISSN 0048-1262

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