Science & Technology HIGHLIGHTS

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ORNL's EE/RE Program: Partnering to Deliver Results

The Energy Efficiency and Renewable Energy (EE/RE) Program at Oak Ridge National Laboratory was established in 1978. Its mission is to accelerate the development of sustainable energy technologies to create a cleaner environment, a stronger economy, and a more secure future for the nation. The program's mission reflects the U.S. Department of Energy's commitment to expanding energy resource options and to improving efficiency in every element of energy production and use.

The program employs an integrated approach to achieve its mission: it combines research with technology development and deployment activities; it draws on the expertise of multidisciplinary teams capable of tackling large and complex problems; and it involves a wide array of industrial, academic, and public-sector partners in defining, executing, and assessing its activities.

The EE/RE Program's major R&D areas include the following:

- Buildings: heating, cooling, and refrigeration systems; appliances; roofs, walls, and foundations; residential weatherization; integrated building systems; and outreach
- Industry: bioprocessing, electric motor and drive systems, advanced turbine systems, advanced materials, sensors and controls, industrial heat pumps, and technical assistance
- Transportation: advanced automotive and heavy vehicle technologies, lightweight materials and high-temperature propulsion materials, alternative fuels, and transportation data and policy analysis
- Electric Utilities: high-temperature superconductors, biomass for power generation, transmission and distribution systems, electric and magnetic field effects, international programs, hydropower, and hydrogen

The Program's primary sponsor is DOE's Office of Energy Efficiency and Renewable Energy. Its DOE funding is strategically leveraged by numerous partners.

One popular mechanism for collaborating and leveraging is the CRADA (cooperative research and development agreement)—a partnership between ORNL and one or more partners, who pool resources with DOE to solve problems of mutual interest. Four National User Facilities also offer opportunities for collaboration. One of these, the High Temperature Materials Laboratory, is featured on page 8. Each of the others will be described in future issues.

Director's Letter

Dear Reader:

Welcome to the first issue of "Science & Technology Highlights," the newsletter of the Energy Efficiency and Renewable Energy Program at Oak Ridge National Laboratory.

This newsletter is intended to be a forum for timely communication of highlights and achievements of our R&D program and our partnerships with industry. Typically, this sort of information has been communicated in a manner more traditional for R&D organizations, such as technical reports and peer-reviewed journal articles. In 1995, we published a summary of program activities and accomplishments. Faced with the need to update that document, we decided that a newsletter published quarterly would be a more timely mechanism and would reach a broader audience. This newsletter is also available on the World Wide Web (www.ornl.gov/Energy_Eff), and we encourage you to visit the site to read the newsletter and other information available there.

ORNL's EE/RE Program covers a broad spectrum of energy efficiency and renewable energy technologies. These technologies are applicable to just about every aspect of everyday life—the homes we live in, the buildings we work in, the cars we drive, and the products we buy. The program's research truly embodies the ORNL motto: *Bringing Science to Life*.

We hope you enjoy reading the newsletter as much as we enjoy telling you about the Program's achievements. We welcome your comments, suggestions, and criticisms (although we hope there won't be too many of the latter). This newsletter is presented to serve your information needs. Let us know what you think!

Anthony C. Schaffhauser, Director
Marilyn A. Brown, Deputy Director
Energy Efficiency and Renewable Energy Program
Oak Ridge National Laboratory

Refrigeration Systems: Opportunities Inside and Outside the Box

ORNL's refrigeration systems program aims to develop the advanced technology base needed to reduce the energy required for building space conditioning and water heating while completing a transition to non–ozone-depleting refrigerants. DOE, ORNL, and our industry partners seek to cut annual energy usage for these applications by at least 25% by 2015–2020.

ORNL is working on advanced technology for household refrigerators (see highlight) and unitary heat pump and air-conditioner equipment. ORNL and DuPont have developed a refrigerant blend that could increase heat pump/air-conditioner cooling efficiency at high ambient temperatures by at least 10 to 15% over their performance with R-410A (the leading candidate to replace R-22). Our goal is to demonstrate this performance enhancement in a packaged air conditioner.

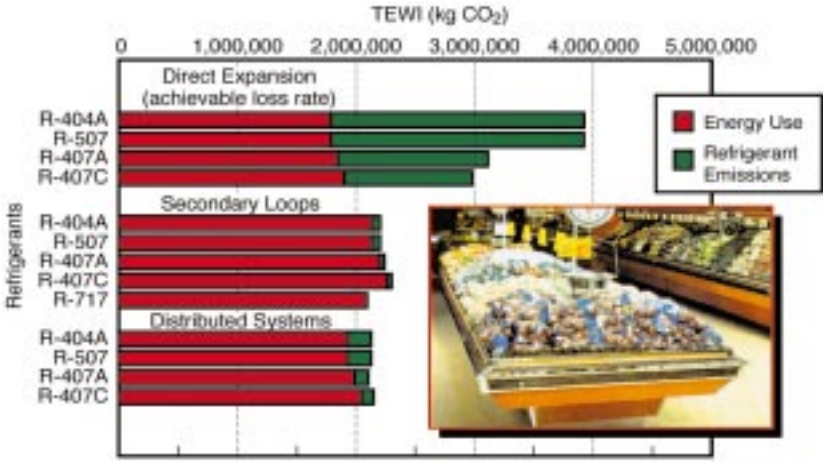
Another effort focuses on system modeling tools. The DOE/ORNL Heat Pump Design Model (HPDM) is used by companies representing about 30% of the market for new equipment design. We are developing a web-based interface for the HPDM and plan to develop Windows-interface versions in response to expressed needs of industry and other users.

The ORNL-patented liquid overfeed (LOF) cooling technology has been shown to improve air-conditioner capacity by 12% and to reduce energy consumption in soda vending machines by 12%. We are evaluating the potential of LOF to improve the efficiency of heat pump water heaters.

In collaboration with chemical manufacturers, ORNL has assessed the global warming impacts of non–ozone-depleting refrigerants. In addition, ORNL has developed an index, Total Equivalent Warming Impact (TEWI), that combines the effects of direct refrigerant emissions with those of CO_2 emissions from energy use.

TEWI is gaining wide international acceptance as the preferred means to evaluate warming impacts. Our research indicates that, for most applications, increasing energy efficiency reduces warming more effectively than using low–global-warming refrigerants.

The effects of refrigerant emissions remain significant, however, in supermarket refrigeration (see figure). A new activity is under way to evaluate and demonstrate the effectiveness of advanced refrigeration systems in reducing TEWI.



TEWI for low-temperature supermarket refrigeration for current systems (direct expansion) and potential reductions with advanced system concepts (secondary loops, distributed systems).

Other new projects involve analyzing alternatives to the standard vapor compression cycle [with the Air-Conditioning and Refrigeration Institute (ARI)] and investigating integrated heating/cooling/water heating systems and low-cost heat pump water heaters (with the Alabama Power Company and Arthur D. Little).

In the future, we plan to focus "outside the equipment box" to identify conservation opportunities through a systems approach: integrating the design of heating and cooling equipment with the building's thermal envelope and thermal distribution and ventilation systems. We are developing this initiative in collaboration with DOE and ORNL programs in thermal envelopes and building retrofit and in connection with the ARI's R&D initiative, "HVAC&R Research for the 21st Century."

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Sponsor: Office of Building Equipment

Fridge of the Future: The One kWh/Day Domestic Refrigerator-Freezer

A "fridge of the future" that uses half as much energy as current models has been designed and demonstrated at ORNL. It is the outcome of an industry-government CRADA to evaluate and test energy-saving design concepts for a refrigerator-freezer (RF) that represents 60% of the U.S. market.

The goal was to demonstrate advanced technologies that reduce by 50% the 1993 National Appliance Energy Conservation Act (NAECA) standard energy consumption for a 20 ft^3 top-mount, automatic-defrost RF. The goal translates to an energy consumption of 1 kWh/d. In 2001, NAECA regulations

Fridge (continued on page 11)

Walls and Building Materials: More than the Sum of the Parts

ORNL's research on walls and building materials is part of a comprehensive R&D effort involving the whole building envelope—walls, roofs, foundations, insulation, and materials, and how they interact to influence energy use. (Roofs and foundations will be discussed in future issues.) Much of the R&D is conducted in the Buildings Technology Center (BTC), a National User Facility with unique capabilities for measuring the properties and performance of systems and materials.

ORNL advances the technology of property measurement and provides leadership in developing standards for the American Society of Testing and Materials. We provide guidance to builders and consumers through widely disseminated publications. Handbooks for designers and builders discuss moisture control in wall systems and foundation design. The consumer-oriented "Insulation Fact Sheet" was updated recently; 100,000 copies were distributed, and it is available at www.ornl.gov/roofs+walls/insulation/.

The state-of-the-art equipment in the BTC is vital to a major initiative, whole-wall R-value labeling. ORNL has developed a system for determining the energy efficiency of walls that accounts for the effects of details such as windows, doors, and corners. Such information is crucial to enable home buyers to compare different materials and construction methods because the wall structure may be considerably less energy efficient than the insulation that fills it. In collaboration with 12 companies, ORNL has tested 50 different wall systems (for more information, see www.ornl.gov/roofs+walls).

In the area of advanced materials, ORNL is investigating vacuum insulation panels, consisting of a porous filler inside a vacuum barrier from which the air is evacuated. Because the panels provide high thermal resistance in a small package, they could be used where space is tight, as in refrigerator doors and walls or manufactured homes. We are also helping eliminate chlorofluorocarbons (CFCs) and related compounds from the production of building materials. Until recently, closed-cell foam insulation was made using CFCs. ORNL is evaluating the performance of foams made with "third generation," or non–ozone-depleting, CFC substitutes.

New research involves evaluating the use of low-cost, locally available materials to insulate buildings. The accompanying highlight describes a recent project to measure the thermal performance of a straw bale wall.

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Sponsor: Office of Building Systems

High R-Value for Straw Bale Walls Confirmed

Tests of a straw bale wall conducted recently in ORNL's BTC provided valuable information about building with this alternative material while at the same time contributing to the development of the next generation of scientists.

During the summer of 1996, a group of teachers studying at ORNL built an 8×8 ft straw bale wall, carefully following the guidelines in a popular straw-building handbook. However, when the thermal resistance of the wall was tested, the result was a disappointing R-value of 14, compared with R-30+ values achieved by other researchers.

To resolve the discrepancy, BTC researchers measured two fundamental material properties (thermal conductivity and air-flow permeability) and used a computational fluid dynamics code to analyze air movement inside the wall from natural convection. Including those factors in the calculations reduced the predicted R-value to R-29. When the impact of air gaps between the straw and the other materials (stucco and drywall) was included, the predicted R-value was R-7 to R-29, depending on the width of the gaps. Because the low R-value of the first wall appeared to be due to air gaps, a second straw-bale wall was built in the spring of 1998 with special attention to eliminating these air gaps. Sure enough, the second wall tested at R-28.

Students in two schools, Green Magnet School in Knoxville, Tennessee, and International Relations Lyceum No. 51 in Kiev, Ukraine, were invited to share in this experiment. They, along with students in other schools around the world, took part via

the Internet in a virtual classroom. They saw live pictures of the wall being built (updated every 15 seconds), video-conferenced with subject matter experts, and had real-time chat sessions and an online forum with ORNL scientists. Students then used test data to determine the wall R-value using the ASTM C 236 data analysis procedure. BTC researchers hope they can continue to make experiments available as educational tools to allow science students to experience real-world research in progress.

By: André Desjarlais and Ken Wilkes
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Industries of the Future

The Industries of the Future (IOF) program was established in 1995 by the Office of Industrial Technologies to facilitate cooperation between DOE/EE and industry. It provides a framework within which the two groups can leverage resources to reduce energy consumption and costs, reduce harmful waste and emissions, and advance U.S. industrial competitiveness.

The IOF program recognizes the importance of a long-term perspective and an integrated approach to address the research and advanced–technology-related issues of energy, the economy, and the environment for the future of the United States. IOF's objective is to align DOE's R&D portfolio with the needs of U.S. industry, within the bounds of the federal government's energy and environmental missions. Industrial participants develop a vision of the technology advances that industry needs to meet business and social goals. Then technology "road maps" are drawn up, setting out specific, prioritized action areas to meet the goals contained within the visions. DOE consults those documents in deciding which R&D initiatives to pursue over the near and long term. DOE typically invests in technology areas where the benefits to the public are potentially large but risks are high. Most projects involve cost-sharing between industry and government.

Government/industry cooperation makes it easier to develop and commercialize high-priority technologies, reducing the cycle time for moving from concept to product. It allows more efficient use of scientific and technical resources and facilitates innovative approaches to meeting environmental objectives.

Nine industries participate in the IOF process: forest products, agriculture, steel, aluminum, mining, metal casting, glass, chemicals, and refining. Together these industries consume 81% of the energy used by manufacturing in the United States and generate 80% of the waste and emissions.

ORNL is providing technical assistance to six of these industries. This assistance is coordinated by ORNL team leaders with contacts throughout the Laboratory. It includes efforts in such areas as instrumentation and controls, materials, fabrication, engineering technology, and advanced computing.

Future issues will describe ORNL activities in each of the IOF industries.

Industries of the Future
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Sensors and Controls for Automated Manufacturing Processes

In concert with DOE and U.S. industries, ORNL has been developing sensor and control technologies and providing technical assistance for the formation of the Sensors and Controls Program. This crosscutting R&D effort, funded through the Office of Industrial Crosscut Technologies, is aimed at developing integrated measurement and control systems for automated control of manufacturing processes. Emphasizing applicability across industries, it will focus on enabling technologies to enhance process knowledge, ultimately increasing efficiency and reducing waste.

ORNL has been developing an advanced, non-contact temperature measurement system that will allow steel mills to more tightly control their galvanizing and galvannealing lines. Capable of measuring temperatures on moving surfaces very accurately, it will result in significant reductions in energy usage and increased product quality.

Another technology under development at ORNL uses sophisticated camera- and laser-based on-line product inspection to evaluate the uniformity and quality of paper as it is formed from wood pulp. By allowing manufacturers to optimize paper characteristics early in the process, it will enhance quality and reduce wasted energy and machine time. Both of these emerging technologies will meet needs in other industries as well, including temperature or inspection measurements on moving aluminum or glass.

Working with industrial associations and instrumentation manufacturing societies, the Sensors and Controls Program intends to develop technologies to meet needs identified in the IOF road maps for individual industries. Particularly needed are improved technologies both for sensors—including embedded, high-temperature and harsh environment applications—and for processing information from different sensory modalities (methods of measuring physical phenomena) to detect and remedy equipment malfunctions and product defects on line.

By 2004, in cooperation with other federal programs, the Sensors and Controls Program will demonstrate the capabilities of a next-generation intelligent control system. Beginning in 1999, the program will begin a 10-year cycle of development and deployment of measurement, control, and automation products for the materials and processing industries.

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Take The Challenge—The Motor Challenge!

Motor-driven systems are the backbone of industrial operations in the United States. Improving the energy efficiency of motors and systems could have a dramatic impact on energy consumption and environmental quality:

- U.S. industry uses more than 40 million electric motors.
- Motors use almost 70% of the electricity used by industry.
- Industry spends almost $30 billion each year on electricity for motor-driven systems.
- About 20% of all electricity bought in the United States is bought by industry to run motors.

To capture these opportunities, DOE began The Motor Challenge, a voluntary government–industry partnership. Its goal is to improve the energy efficiency of industrial motor-driven systems. The program is unique in two ways. First, the degree of DOE–industry interaction in establishing the program was unusual at the time. Second, the program addresses *system-level* rather than *component-level* needs. For example, a motor-driven system might contain a motor and equipment such as fans, blowers, or pumps. Motor Challenge seeks to improve the efficiency of the entire system, rather than of the motor only.

So far, more than 1000 organizations have partnered with DOE, and 25 showcase demonstrations are completed or under way. Completed demonstrations account for a estimated $2 million in energy cost savings annually. Because of its success, the program is being extended to include compressed air systems and steam systems. The Compressed Air Challenge, still in its first year, has an energy savings goal of 10% over current usage, equivalent to annual savings of approximately 3 billion kWh. The Steam Challenge is just getting under way.

ORNL plays a key role in many aspects of the program—information resources, tools, and training—but has focused mainly on information resources and training. ORNL staff validate and document the performance of proposed Showcase Demonstration projects (see the highlight on this page).

ORNL has also developed training materials and seminars on pump system optimization. One seminar features a software tool developed by ORNL called ORMEL (Oak Ridge Motor Efficiency and Load) that uses a proprietary method to convert nameplate data into a motor equivalent circuit. The operating efficiency and load can then be estimated accurately using only a speed measurement. ORMEL allows evaluation of a motor's performance on the shop floor without disrupting operation. It is 10 times more accurate than the most commonly used tool, the slip method.

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Sponsor: Office of Technology Access

ORNL Team Validates Savings in Showcase Demonstration Projects

Participants in Motor Challenge identified a need for information on improvements in specific industrial processes that are validated and documented by an independent third party. Motor Challenge established its "Showcase Demonstrations" to meet that need.

The demonstrations target improvements in the efficiency and productivity of systems driven by electric motors. They are projects at an industrial partner's facility that involve one or more motor systems. An ORNL team validates and documents the results of the demonstration.

ORNL staff obtain "before and after" data on system performance from the industrial partner and analyze them to verify and document the energy, environmental, and economic performance of the project. ORNL's analysis documents actual energy and cost savings, as well as such other benefits as production improvements and waste reduction. Each project and the analysis are documented in a brief report that is widely distributed. Reports of completed demonstrations are available at www.motor.doe.gov/mcshow.htm.

Performance Improvement Summary		
Annual Energy and Cost Savings		
Electricty	443,332 kWh	$35,700
Natural Gas	17,840 therms	$26,500
EMS Maintenance Contract		$ 5,800
Total		$68,000
Total Annual Emissions Reductions		
CO_2	470,600 lb	
Carbon Equivalent	128,350 lb	
SO_x	1,400 lb	
NO_x	890 lb	
TSP	140 lb	
VOC	30 lb	
CO	190 lb	

The first Showcase Demonstration to be completed successfully was a project to improve the performance of the ventilation system in a plating facility at Lockheed Martin Armaments Systems. The existing system was designed for continuous 24-hour operation at a constant speed; but the plant was only operating for one shift daily, and the combination of tanks in use varied. The company installed variable frequency drives in conjunction with an energy management system to allow the speed of the ventilation fans to fluctuate with the need for ventilation. The energy management system detects when plating tanks are not being used and slows the exhaust fans and makeup air units for those lines accordingly.

The new system has reduced utility costs by 38%, improved the operating efficiency, reduced emissions, and improved the work environment (see table). The project cost about $99,400 and has resulted in annual savings of more than $68,000, for a simple payback of less than a year and a half.

By: Mitch Olszewski
Sponsor: Office of Technology Access

Emissions Research: Keeping It Clean

ORNL's R&D efforts in automobile and engine emissions are comprehensive, spanning many disciplines, scales, and facilities. We are engaged in projects to quantify and characterize emissions, as well as research to mitigate them. For example, we study the microstructure of emissions control catalysts at the atomic level, evaluate catalyst powders and core samples at the bench scale, measure the effectiveness of full-scale catalytic converters in engine dynamometer cells, and perform emissions tests on complete vehicles.

ORNL is able to examine the quantity and nature of exhaust emissions in great detail and is doing so in several projects. We have seven active CRADAs with industry, plus one more under development, directly pertaining to emissions reduction or measurement. The subjects of these agreements provide evidence of the breadth of the ORNL activities: ignition modeling, NO_x catalyst R&D, engine combustion dynamics, and turbocharger performance enhancement. Other CRADAs exist in materials technology, frequently a key "enabler" for emissions control systems. We also conduct research for DOE to provide data in open forums to support policy decisions and technical planning. This research spans the subjects of NO_x sensors; exhaust gas recirculation dynamics; and improvements in characterizing the size, shape, and condition of fuel injector nozzles.

Recent achievements in the Advanced Propulsion Technology Center have paved the way for effective emissions mitigation. A technology called "laser phosphor thermography" allows scientists to measure the temperature of parts inside an operating engine in real time. Our scientists have developed instruments for measuring nitrous oxides and hydrocarbons in exhaust, also in real time. (Real-time measurements allow researchers to see the effects of changes immediately.) ORNL has been issued a patent on an emission-reducing fuel formulation, has developed in situ measurements of the oil film on the walls of the engine cylinders, and has comprehensively mapped the emissions and fuel economy of a modern diesel auto.

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Sponsors: Office of Advanced Automotive Technologies, Office of Heavy Vehicle Technologies

NO_x Catalysts for the Car of the Future

ORNL is working with U.S. auto companies, diesel engine manufacturers, and other national laboratories to develop the lean, clean car of the future.

Today's compression-ignition, direct-injection diesel engine is a prime candidate for fuel-efficient vehicles of the future because it uses 35 to 40% less fuel per mile than gasoline-burning spark-ignition engines. The challenge is that diesel engines emit high levels of particulates and nitrogen oxides (NO_x), which contribute to smog and acid rain. Catalytic converters remove NO_x from exhaust efficiently, but they are incompatible with today's diesel engines.

Materials scientists at ORNL are evaluating the microstructures of a new generation of catalysts to understand why they perform well or poorly. Researchers at the Advanced Propulsion Technology Center are using gas chromatography, mass spectrometry, and Fourier transform infrared spectroscopy to determine whether test catalysts remove NO_x effectively from exhaust.

An initial finding is that, for diesel fuel, precious metal catalysts work well at too low a temperature, while metal-oxide catalysts work well at too high a temperature, suggesting that the best treatment may combine the two catalyst types. ORNL researchers have also identified hydrocarbons in unburned diesel fuel that enhance catalyst performance. The hydrocarbons react with NO_x to form nitrogen, carbon dioxide, and water vapor. Researchers are evaluating techniques to introduce the right hydrocarbons to the exhaust system at the proper time to optimize the performance of the chosen catalysts.

ADVANCED PROPULSION TECHNOLOGY CENTER

ORNL's Advanced Propulsion Technology Center (APTC) is where the "rubber meets the road" on transportation R&D projects. The facility houses the engine hardware for R&D in which it is critical to conduct experiments with or in real systems. Prototypes of sensors, emissions control devices, fuels, and new types of engine diagnostics have been studied, developed, and scrutinized here.

Our collaborators at the University of Tennessee provide chassis dynamometer capability. Using the University's dynamometer in combination with on-road tests, ORNL has pioneered uniquely comprehensive maps and models of vehicle emissions and fuel economy.

The APTC has perhaps the most complete array of emissions measurement equipment of any DOE laboratory. Three types of instruments are available for measuring particulate matter (PM) emissions and particle size from diesel engines, and two more are expected to come on line within a year. The diesel engine is the most efficient, cost-effective powerplant known, but it generates more NO_x and PM than future regulations will allow. The reasons are complex, involving the characteristics of the fuel as much as the engine design; the APTC will be useful in addressing this challenging issue.

Most of the R&D conducted in the APTC is done through CRADAs with U.S. auto and engine manufacturers. Certification of the APTC as a National User Facility is pending; if it is granted, industrial partners will be able to use the laboratory facilities for a fee. Companies in the United States can also receive up to four days of technical assistance, at no cost, through the Direct Assistance Program. To contact this program, call 1-800-356-4USA (4USA@ornl.gov).

Power Electronics: Cheaper, Smaller, Faster

ORNL's power electronics R&D program emphasizes components that will be part of hybrid electric vehicles. Improved motors, controllers, and inverters are critical technology needs if electric vehicles are to be an everyday sight on U.S. highways. They must be smaller, lighter, and faster than today's power electronics.

ORNL is a key player in the DOE Office of Advanced Automotive Technologies program to develop an automotive integrated power module. The program goal is to develop revolutionary power electronics and electric machinery technologies that reduce the cost, volume, and weight of these components while increasing their reliability and performance. Current research projects include

- a broad-range, isolated bi-directional dc-dc converter for use with auxiliaries in a fuel-cell-powered vehicle
- deployment of ORNL's advanced inverter technology in an electric bus
- system voltage analysis of hybrid vehicles
- field weakening and magnet retention of permanent magnet motors
- switch reluctance motor and drive R&D
- motor and drive modeling and simulation in hybrid vehicle subsystems
- power converter packaging and topology R&D.

Much of the R&D is conducted in ORNL's Power Electronics Center, a dedicated 6000-ft^2 laboratory. The rest is performed at the facilities of our partners in industry, academia, and other national laboratories.

Because power electronics are so pervasive in our high-tech society, ORNL's power electronics and electric machinery R&D benefits a diverse range of other applications, such as superconducting generators and transformers, adjustable-speed machine drives, and electric power transmission and distribution systems. Perhaps the most exciting advances in our power electronics R&D are being made in inverter technologies. ORNL's advanced inverters (discussed in the highlight) reduce power losses and increase reliability. They are expected to have a wide array of uses, ranging from electric buses to more efficient heat pumps to safer brain surgery techniques.

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Sponsor: Office of Advanced Automotive Technologies

New Inverters Produce "Cleaner" Power

ORNL's power electronics program is developing advanced power inverters that are more compact, cool-running, efficient, and reliable, and that produce less electromagnetic interference, than conventional inverters.

Inverters convert power from direct current to an alternating current controlled at some desired frequency and voltage. Conventional inverters work by switching power transistors on and off while current passing through them or voltage across them is not zero (hard switching), resulting in power losses and heat generation. ORNL has helped develop soft switching inverters in which the voltage across the switch resonates to zero before it switches, reducing the power loss and the heat. Less heat means lighter, cheaper heat sinks can be used and components can be placed more closely together, allowing large weight and volume reductions.

One of the first soft-switching inverters developed at ORNL, the resonant snubber inverter, is about 66% lighter and 90% smaller than conventional units, in addition to being more efficient. It works well with single-phase systems , for which it is being commercialized. ORNL's latest soft-switching technology, the auxiliary resonant tank inverter, can be used with three-phase systems. It has the fewest components and the lowest current stress on components of any soft-switching inverter. It can easily be attached as a module to existing inverters to make them soft-switching if the system being driven requires low electromagnetic or line interference.

Multi-level inverters (MLIs) are being developed for use in high-voltage applications, such as power transmission and conditioning, and as adjustable speed drives for high-voltage industrial motors. They greatly reduce harmonic distortion in electric machinery. MLIs use multiple voltage levels, instead of rapid switching, to synthesize a "clean" high-voltage waveform. An MLI developed at ORNL may prove useful for integrating power from small renewable sources, such as photovoltaic cells or wind turbines, with the higher-voltage utility grid.

Fang Peng and Cliff White demonstrate the suitcase-size ORNL cascade multilevel inverter.

Development of advanced inverters is supported by the Office of Transportation Technologies.

By: Don Adams and John Mckeever, 423-576-1862, mckeeverjw@ornl.gov

Advanced Solutions for Materials Problems

The High Temperature Materials Laboratory (HTML) is a specialized facility designed to help users develop advanced materials. Home to an expert staff and numerous sophisticated, unique pieces of materials-characterization equipment, the HTML is a designated National User Facility sponsored by the Office of Transportation Technologies. Since its inception, researchers from almost 400 organizations have used this state-of-the-art facility.

The HTML is a 64,500 ft^2 building with six "user centers," or clusters of specialized equipment for specific types of properties measurements. It was established in the 1980s to work directly with American industry, academia, and government laboratories to develop advanced high-temperature materials, such as structural ceramics for energy-efficient engines. The scope has expanded to include other materials of interest to industry. Ceramics, metal- and ceramic-matrix composites, lightweight materials such as aluminum and magnesium alloys, steels, and electronic materials have been characterized.

Within the HTML are programs to help researchers solve materials problems using the latest characterization instruments. Research can be either nonproprietary or proprietary. The former is free if the results are published. For proprietary research, the user and HTML staff estimate the cost of the staff time required, for which DOE sets an hourly rate. The user retains ownership of the data resulting from proprietary projects. Work is done for other DOE branches via direct funding or CRADAs. The HTML can characterize materials for a user on a noncompetitive, full-cost-recovery basis under a work-for-others agreement. To find out how you can use the HTML, check out www.ms.ornl.gov/htmlhome or call Billie Russell at 423-574-1926.

The User Centers

Researchers in the Materials Analysis center use electron microscopy and surface chemical analysis to determine structure, surface chemistry, and microstructure to the atomic level. Advanced microscopy capabilities allow rapid, direct elemental analysis of grain boundaries in metals and ceramics. Auger spectroscopy and atomic force microscopy instruments are available for analyzing material surfaces. R&D staff are

Solutions (continued on page 10)

Remote Instrument Operation in the HTML

The HTML is leading a paradigm shift in the way scientists conduct research. Remote instrument operation has been developed to create a "virtual laboratory." Using inexpensive PCs and software over the Internet or dedicated telephone lines, users at remote sites can operate instruments at the HTML—for example, a million-dollar transmission electron microscope too costly for all but the largest laboratories.

Remote users also can monitor neutron residual stress data being collected at the ORNL High Flux Isotope Reactor, or operate scanning electron microscopes, an electron microprobe, and mechanical test instruments.

A new initiative at ORNL, DOE2000, seeks to develop virtual laboratory concepts for use in DOE research. One of two pilot programs selected for DOE2000 was the Materials MicroCharacterization Collaboratory (MMC), which demonstrates the use of technologies such as remote electron microscope operation, video teleconferencing, and electronic white boards in collaborative materials research. One focus of the MMC is the characterization of NO_x reduction catalysts. The MMC combines unique characterization tools and experts to provide near real-time insights into materials performance.

HTML staff are implementing hardware and software for the MMC to facilitate the use of HTML instruments already available on line and to bring other instruments on line. The staff provide guidance for research using virtual laboratory tools that relate catalyst microstructure to performance.

Three other HTML National User Program projects (two with Ford and one with Valenite) involve distance transmission electron microscopy. The work with Ford and the MMC have already advanced NO_x reduction catalyst research. A collaboration between Ford, ORNL, and Argonne National Laboratory has produced a catalyst with superior structural characteristics (e.g., precious metal distribution) that is being evaluated for stability at high temperatures in exhaust gases.

Vice-President Al Gore operates the HTML Hitachi high-resolution transmission electron microscope from the ORNL central library with the assistance of HTML staff member Larry Allard during Mr. Gore's recent visit to ORNL.

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Sponsor: Office of Heavy Vehicle Technologies and Energy Research—Mathematical Information and Computational Sciences Division

High-Temperature Superconductivity–Inventing the Future

ORNL's Superconductivity Technology Program is part of DOE's effort to develop the science and technology base to enable U.S. industry to market electric power applications of high-temperature superconductivity. ORNL focuses on working with industrial partners to develop superconducting wire and power applications based on superconductivity, such as transformers, motors, generators, and electrical cables.

Some 75% of ORNL's superconductivity research involves partnerships with private companies; several of these also involve interlaboratory teams. ORNL has entered into 46 CRADAs (10 still active) with private partners since the program's inception in 1988-89 amounting to an estimated $20 million in cost sharing from industry. ORNL and its industrial partners have filed about 60 invention disclosures as a result of research conducted through the superconducting program.

A highlight of the efforts to develop second-generation superconducting wire with the "coated conductor" approach is the four-party CRADA involving the 3M Company, Southwire, and Los Alamos National Laboratory. For this, ORNL has developed a process for depositing superconducting material upon a rolling-assisted, biaxially textured substrates (RABiTS®) template. The 3M Company has developed the ability to produce this template in kilometer lengths and is scaling up the superconducting film deposition process. Two patents were issued in 1998 for the RABiTS template.

A highlight of efforts to develop pre-commercial prototypes of superconducting equipment is ORNL's work with Southwire to design a first-generation high-temperature superconducting (HTS) cable. ORNL will complete testing this year on 5-m-long segments of the bismuth-strontium-calcium-copper oxide cable. Then Southwire will install and demonstrate a 30-m 12.5-kV, 1250-A length of the cable for testing under real-use conditions in its manufacturing complex by the end of 1999. A second highlight is the testing of the first HTS transformer now under way at Waukesha Electric Systems (see the highlight).

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Sponsor: Office of Utility Technologies

First HTS Transformer Tested at Waukesha

A high-temperature superconducting (HTS) transformer developed by ORNL and its partners holds the potential to cut power transmission losses substantially and deliver power more reliably and safely in the bargain.

ORNL, transformer manufacturer Waukesha Electric Systems in Wisconsin, Intermagnetics General Corporation, and Rochester Gas and Electric Company designed and built a 1-MVA prototype HTS transformer now being tested in Waukesha's laboratory. It is a testbed to evaluate various innovative components required for eventual commercial introduction of HTS transformers.

The unit uses superconducting wire held to 20 to 35K by a cryocooler and liquid nitrogen (20K = -253°C). The tests have confirmed the technical feasibility of a unique "cryocooled" approach first suggested and engineered by ORNL. So far, the transformer has proved capable of delivering 0.7 MVA actual power. In tests in early 1998, it was energized to 11,000 primary volts and, separately with augmented cooling, to 150 primary amperes (over twice its rated normal current) for an indicated power delivery capability of 1.7 MVA. Additional tests are planned this summer.

The cooling system has given ORNL's industrial partners a competitive edge in this breakthrough technology. The successes have given ORNL's team members confidence to proceed to the next phase, developing a pre-commercial, 5-MVA transformer to power the Waukesha plant in the year 2000. ORNL again will lead several project tasks.

HTS transformers are more efficient than conventional units because superconducting wire does not resist electrical flow.

Super-conducting transformer prototype being tested at Waukesha.

Unlike conventional transformers, which deteriorate when even briefly overloaded, they can run continuously at rated capacity and indefinitely beyond rated capacity (with additional cooling) without damage. HTS units are smaller and lighter. Finally, they avoid the environmental hazards associated with oil-filled transformers, and the high costs of oil containment and fire protection. Those attributes make them particularly attractive for use inside buildings and in crowded areas.

Waukesha hopes to bring this technology to market by 2002.

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Geothermal Heat Pumps: Super Project and Super ESPC

The word's largest installation of geothermal heat pumps (GHPs) is proving this energy-efficient technology to be cost-effective. Between March 1995 and August 1996, the U.S. Army, in conjunction with the energy services company Co-Energy Group, used $18.9 million worth of private capital to retrofit 4003 family housing units on the Fort Polk, Louisiana, military base with geothermal heat pumps (GHPs). This massive project led to the development and manufacture of higher-efficiency GHPs configured for low-cost installation and maintenance and provided a test bed for ground heat exchanger design methods and advanced installation techniques.

ORNL conducted an independent evaluation based on aggressive data collection before, during, and after the retrofits with sponsorship by the Department of Defense and DOE's Office of Utility Technologies. Statistically valid findings indicate that the GHP systems, in combination with other energy retrofit measures, have reduced annual whole-community electrical consumption by 33%, natural gas consumption for space and water heating by 100%, and summer peak electrical demand by 43%. The energy and demand savings correspond to an improvement in the whole-community annual electric load factor from 0.52 to 0.62. Fort Polk incurred no up-front capital cost, saves about $345,000 annually in operating costs, benefits from completely new heating and cooling equipment, and is guaranteed maintenance of those systems for 20 years. (The methodology and results of the evaluation are documented in the reports ORNL/CON-460 and ORNL/CON-462.)

The evaluation uncovered research needs that ORNL is addressing:

- To size vertical borehole ground heat exchangers (BHExs), designers need to know the borehole thermal resistance and the thermal properties of the soil/rock formation. To supply these data, a service company can install a BHEx at the site, impose a thermal load, take data, and calculate the thermal resistance and formation properties. However, the data sets generated by these companies are inconsistent.
- Several commercial methods of sizing BHExs recommend different sizes even when the data inputs are consistent.
- Mainstream building energy analysis methods represent GHP systems inadequately, making it difficult for designers to estimate the financial value of the systems accurately.

A rig drills boreholes for installation of polyethylene pipe for geothermal heat pump installations at Fort Polk.

ORNL is approaching these problems by establishing benchmarks based on data from actual operating GHP systems against which the commercially available services and software can be compared.

Resolving the research issues will encourage smaller design safety factors and more economical GHP applications, but the Fort Polk project demonstrates that the current GHP state of the art provides significant financial benefits to the federal government. As a result, DOE's Federal Energy Management Program is sponsoring ORNL to provide technical support for the "National GHP Technology-Specific Super ESPC [energy savings performance contract] Procurement." The request for proposals was released June 1, 1998. Federal agency sites throughout the 50 states, the District of Columbia, and U.S. territories will soon be able to acquire privately financed GHP-centered ESPC projects via delivery orders against contracts resulting from this solicitation.

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Solutions (continued from page 8)

pioneering a capability called "remote microscopy," which allows users to control the center's microscopes from remote locations, such as their offices (see highlight on page 8).

In the Mechanical Characterization and Analysis center, users study fracture toughness, tensile strength, flexure strength, and tensile creep of advanced materials at temperatures to 1500°C in air or controlled atmospheres. Instruments are available to study fiber-matrix interactions in both metal and ceramic matrix composites.

The Residual Stress center offers unique capabilities in x-ray diffraction and neutron diffraction. The x-ray facility includes x-ray diffractometers to measure residual stress and texture in and near the surface of ceramics and alloys. Two systems provide highly flexible sample tilt systems and either a divergent or a parallel beam. Users can access the National Synchrotron Light Source at Brookhaven National Laboratory,

Solutions (continued on page 11)

Fridge (continued from page 2)

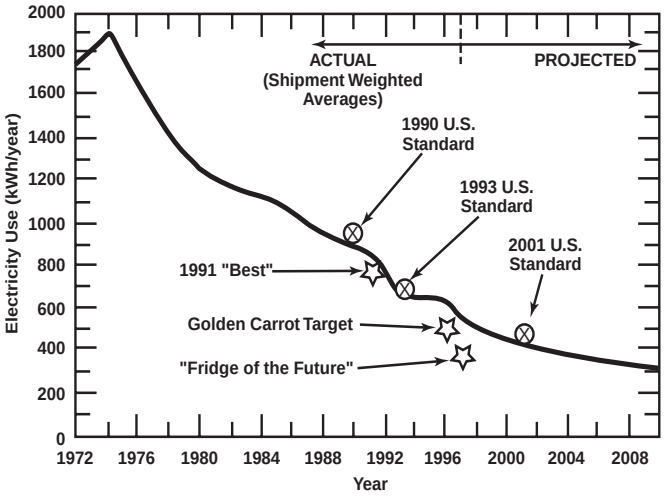
will require a 30% reduction in energy consumption. Thus the CRADA is expected to exceed the new regulations.

The new technologies were investigated in a prototype RF cabinet and refrigeration system. The baseline energy consumption of the original 1996 production RF, along with cabinet heat load and compressor calorimeter test results, were extensively documented to provide a basis for experimentally measured energy savings. Based on input from manufacturers, a laboratory prototype was fabricated and tested to verify the energy consumption of a unit with vacuum insulation around the freezer, increased door thicknesses, a high-efficiency compressor, a low-wattage condenser fan, a larger counterflow evaporator, and adaptive defrost control.

The resulting energy consumption was 0.928 kWh/d, an efficiency improvement of 45% over the 1996 model baseline unit (1.676 kWh/d) and 54% better than the 1993 NAECA standard for 20 ft^3 units (2.006 kWh/d). The cost for these improvements was estimated to be approximately $134 (manufacturer's cost).

A second design eliminated the vacuum panel insulation and larger evaporator. It reduced energy use to 1.164 kWh/d at a manufacturer's cost increase of $53. Assuming a 100% markup from manufacturer's cost, the payback for this unit is approximately 6.6 years.

News of the 1 kWh/day refrigerator was released in April, following the announcement of the new federal standard for



The electricity consumption of household refrigerators.

refrigerators. Secretary of Energy Federico Peña heralded the achievement, saying, "Last week I announced efficiency standards for the 'fridge of the 21st century,' and this week Oak Ridge is helping us meet these standards through public-private partnerships. Top quality appliances save money on power bills and protect the environment for future generations."

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Solutions (continued from page 10)

where ORNL maintains a beamline with structure and residual stress analysis capability. The neutron portion includes a neutron spectrometer for rapid data collection and computing capabilities for data analysis. This facility allows users to measure and map stress fields inside large solid objects.

The Diffraction center has both room-temperature and furnace-equipped x-ray and neutron diffractometers. The x-ray furnace is used to study materials properties at temperatures up to 2700°C in vacuum and 1500°C in air.

Researchers in the Physical Properties center study thermal stability, expansion, and thermal conductivity of materials to 1400°C. A laser flash instrument measures thermal diffusivity to temperatures of 1900°C. A thermal conductivity microprobe can determine heat flow in solid surfaces on a scale of a few micrometers. A high-speed, high-sensitivity infrared camera is available to capture thermal events digitally.

The Machining and Inspection Research center uses instrumented surface and cylindrical grinders to study grinding forces and their roles in controlling the topography and mechanical and wear properties of the resulting surfaces. Instruments for determining the cylindricity and circularity of axially symmetric objects are available. A Silicon Graphics workstation is used for extensive computer modeling and graphics. Also available are an instrumented, electrochemical-capable creep feed grinder system for grinding research on ceramics and composites; a coordinate measuring machine; a centerless grinder for prototype manufacturing studies; and equipment for measuring friction and wear, including fretting, rolling, and sliding.

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Late-Breaking News . . .

Conferences and Workshops

Thermal VII Conference

The Seventh International Conference on Building Thermal Envelopes will be December 7–11, 1998, in Clearwater Beach, Florida. The conference will present two tracks—one devoted to research (principles) and a second focused on practical applications and case studies (practices). Full-day special-topic workshops will also be presented. For more information and registration information, see www.ornl.gov/ORNL/Energy_Eff/th7main.htm or contact the conference secretary at telephone 423-576-7942 or unb@ornl.gov.

ACEEE 1998 Summer Study on Buildings

The 1998 Summer Study on Energy Efficiency in Buildings will be August 23–28 at the Asilomar Conference Center in Pacific Grove, California. Refereed papers are presented in the mornings, informal sessions and display sessions in the afternoons, and plenary sessions in the evenings. Marilyn Brown (ORNL) and Helmut Feustel (LBNL) are the co-chairs, and the American Council for an Energy-Efficient Economy is the organizer. For more information go to www.aceee.org/conf.

Publications

OAAT R&D Plan Available

DOE's Office of Transportation Technologies has published *Energy-Efficient Vehicles for a Cleaner Environment: Office of Advanced Automotive Technologies R&D Plan*. This long-range plan provides an integrated approach to the way DOE conducts automotive technology R&D. For further information on the *R&D Plan* or other OAAT programs, call the Office of Advanced Automotive Technologies at 202-586-8055.

The "11-Lab Study"

Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions, a report by the directors of DOE's national laboratories, is available. The main report presents the basis for a climate change technology strategy, and a separate appendix outlines technology pathways to eliminate hundreds of millions of tons of carbon emissions per year. The report is at www.ornl.gov/climate_change. Contact Brenda Campbell at 423-574-4333 or xbd@ornl.gov for more information.

What's your R-value?

Utility bills rise with summer temperatures, but the *Insulation Fact Sheet* provides information to help hold down the costs. The 19-page DOE publication addresses questions about home insulation. A chart provides insulation recommendations based on zip code. The fact sheet is available at www.ornl.gov/roofs+walls. Request a hard copy from the Energy Efficiency and Renewable Energy Clearing House at 800-363-3732.

Events

Heat Treat Project Honored

The Predictive Heat Treatment Distortion Project has received the National Center for Manufacturing Sciences Award for a technically excellent project. The tool developed will aid in predicting of distortion, residual stress, and microstructure in heat-treated and quenched ferrous alloy components. It could save industrial users billions of dollars per year and help reduce energy use, material scrap, design time, and time to market.

Habitat for Humanity Build

In April, the completion of 20 houses by more than 1,000 Habitat for Humanity volunteers in Americus, Georgia, marked the first step in constructing a subdivision of affordable housing in which all homes meet Energy Star standards. ORNL, in cooperation with DOE's Partnerships for Affordable Housing Program, provides Habitat with technical support to incorporate energy efficiency into house plans and construction specifications. ORNL, DOE, and Habitat are gearing up for the 1998 Jimmy Carter Work Project, another build later this year in Houston, Texas.

Science and Technology Highlights
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Smart Composite Natural Gas Vehicle Tanks

On March 31, ORNL hosted a meeting of organizations interested in developing "smart" natural gas vehicle composite fuel tanks. Other participants were DOE, the Gas Research Institute, Battelle, and Thiokol Corporation. The objective was to develop an agreement-in-principle under which the participants would collaborate in developing the technology. A smart tank would use advanced sensors to indicate developing hazardous conditions in composite fuel tanks. For the near term, ORNL will assume the role of coordinator and data clearinghouse for the project.