Science & Technology HIGHLIGHTS

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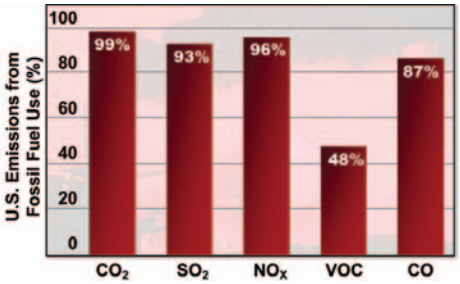
"Negawatts:" The Cleanest Energy Resource

Despite several decades of "clean air" legislation in the United States, air pollution continues to be one of our most serious environmental problems, with adverse effects on human health and environmental systems. The country is



Percentage of major air pollutants that result from fossil fuel use.

experiencing a rise in respiratory illnesses, and 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 advise visitors of the risks of hiking in the Park, and rangers are routinely prevented from working in sections of the Park on ozone alert days. Visibility in the Smoky Mountains now rarely achieves its "natural" limit of 93 miles—annual visibility has decreased in winter to an average of 25 miles and in summer to an average of 12 miles.

ORNL is contributing solutions to improve air quality 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, for example, uses 70% of the electricity consumed in the United States, so energy-saving construction and building equipment technologies can dramatically impact air quality. This issue of *S&T Highlights* has several examples of ORNL's energy-saving technologies for buildings, including advances in water heating, heat pumps, and air-conditioning.

In the industrial sector, advanced materials and processes developed at ORNL have delivered significant reductions in energy use by heavy industry. New technologies such as e-beam curing and processing of metals in magnetic fields (described in this issue) have a high potential for cutting energy use even as they reduce process waste and enhance product performance. ORNL also plays a key role in DOE's Best Practices program that helps U.S. industry minimize its waste streams while it upgrades its energy efficiency.

Distributed energy technologies can more than double today's average electric system efficiency through the use of integrated cooling, heating, and power systems that capture and use waste heat productively instead of venting it to the atmosphere. The improvement in fuel efficiency means corresponding big improvements in air quality. Working with its industrial partners, ORNL has helped demonstrate this potential in an Austin Energy facility described in this newsletter.

Every advance in fuel efficiency and emissions control for vehicles translates into tailpipe emissions avoided. ORNL has an extensive R&D portfolio in advanced technologies to improve the efficiency of internal combustion engines (ICEs) for both transportation and power applications. This *S&T Highlights* describes ORNL's Fuels, Engines, and Emissions Research Center, which is conducting R&D to allow more effective control of ICE emissions without a fuel economy penalty. For the long term, ORNL is contributing to efforts to develop the technologies needed to enable a hydrogen economy.

In the power sector, ORNL is supporting hydropower, geothermal, wind, and biomass technologies that represent clean energy alternatives. The Laboratory also is a leader in developing superconducting technologies that could dramatically improve the efficiency and reliability of the U.S. electric grid. Eliminating the substantial losses that occur as electricity is transmitted from generator to end user will proportionately reduce the need for power generation and associated air emissions.

As the American economy expands and the demand for energy services grows, technologies that generate "negawatts" will be increasingly important, so that our economic advances do not come at the expense of our health and the vitality of our environment.—*Marilyn Brown*

High-visibility conditions in the Smoky Mountains–100 miles (top). Low-visibility–20 miles (bottom).

FEERC: Developing Engines that Consume Less and Pollute Less

The long-term goal for the U.S. energy system is a move to energy sources other than fossil fuels for transportation and electricity generation. In the interim, however, the greatest opportunities for conserving petroleum and reducing the environmental impacts of energy consumption lie in stretching the efficiency of internal combustion engines (ICEs) and clearing the way for the use of non-petroleum fuels.

ORNL's Fuels, Engines, and Emissions Research Center (FEERC), located in the National Transportation Research Center, is a key player in developing improved ICE technology and advanced fuels. FEERC researchers use a unique collection of instruments and computing tools to characterize the minute details of ICE operation to guide the development of cleaner, more efficient engines and advanced fuels. The ultimate goal is combustion engines that can use non-petroleum-based fuels and produce near-zero polluting emissions.

Researcher Robert Wagner with one of the CIDI ICEs in the FEERC collection.

FEERC's work focuses primarily on ICEs in transportation applications but also includes those used to generate electrical power for portable and distributed energy applications. Fuel economy and emissions controls are issues for both technology areas.

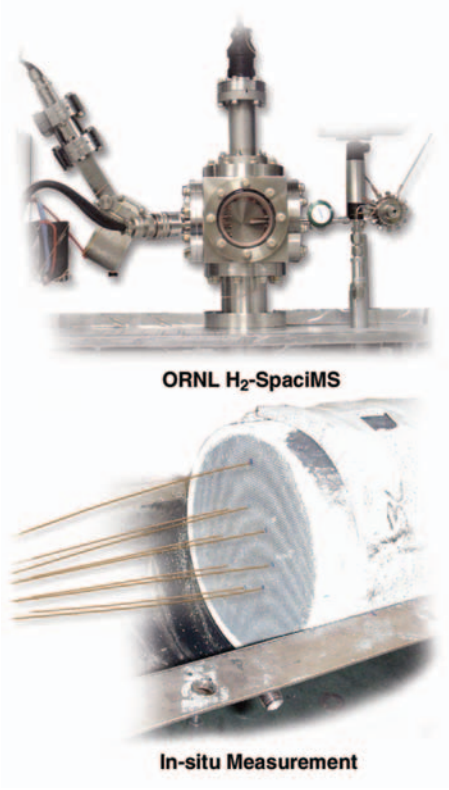
Transportation

The use of light trucks (e.g., pickups and sport utility vehicles) for transportation has increased dramatically; they account for almost half of all vehicle sales, foreign and domestic, in the United States—up from 25% in the mid-1980s. An immediate way to reduce petroleum consumption would be to replace the gasoline engines in light trucks with modern, clean diesel engines, which are 30–50% more efficient. However, expanding the market for diesels depends on controlling their emissions, particularly nitrogen oxides (NO_x). For several years, therefore, FEERC has focused mainly on emissions controls and aftertreatment technologies for diesel engines. Its emissions R&D ranges from fundamental catalyst chemistry through experimentation and modeling at the component, engine, and vehicle level.

FEERC staff have invented unique diagnostic tools to precisely define different ICE exhaust species and their fate as they move through emission control systems. Two such instruments, the SpaciMS and the phosphor thermography instrument, map the constant subtle changes that occur in the chemistry and temperature, respectively, of emissions traveling through a catalyst. Their measurements are rapid and accurate enough to show researchers what is happening inside an operating catalyst. (Other instruments could characterize only emissions entering and exiting the catalyst.) The SpaciMS has been improved recently to measure hydrogen in engine exhaust and within operating catalysts, a rare capability that is providing insights into processes for regenerating NO_x adsorber catalysts.

Research at FEERC on strategies for controlling diesel emissions includes adsorber catalysts for NO_x, urea-selective catalytic reduction, exhaust gas recirculation (EGR), particulate filters, and controls with virtual sensing. The Center's capabilities in engine electronic control prototyping have been used to characterize methods of regenerating lean NO_x traps (LNTs). (LNTs trap and store NO_x during lean engine operation. A rich engine cycle then supplies hydrocarbons that react with the NO_x on a catalyst to reduce it to N_2 and other byproducts.) In the course of these experiments, a method of generating larger quantities of hydrogen in exhaust was developed and confirmed using the SpaciMS. (Hydrogen-rich exhaust reacts with NO_x to produce N_2 and water.) Data from these tests are posted on the CLEERS website maintained by ORNL (see the CLEERS sidebar). Detailed data on how LNTs use exhaust hydrocarbons helped identify a method to tailor exhaust species to lower the fuel penalty during LNT regeneration.

As progress in emissions control addresses the need for research in that area, the R&D emphasis at FEERC is shifting toward fuel economy and advanced combustion regimes. Electronic engine management systems are used to investigate combustion process control and integration of engines and aftertreatment systems. FEERC provided the first publicly available information on methods for operating diesel engines in low-temperature combustion



The SpaciMS maps the constant changes in the chemistry of emissions as they travel through a catalyst.

modes that exhibit low NO_x and soot emissions simultaneously, and has documented the emissions in great detail (see "Cleaner Combustion" sidebar). So far, the research team has been able to maintain good efficiency in low-temperature combustion. Efforts are under way to determine how to exploit new combustion processes for increased engine efficiency.

Characterizing and customizing the properties of fuels and lubricants is another emerging research area. FEERC staff are investigating how shifts in fuel properties affect advanced combustion processes and how fuel and lubricant constituents, such as sulfur and phosphorous, degrade emission control devices. These studies will provide insight into

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Cleering the Air

ORNL is coordinating DOE's research on new simulation tools for catalytic emissions control. As part of that role, the Lab was co-leader (with industry) in forming Crosscut Lean Exhaust Emissions Reduction Simulations (CLEERS) to spur the development of better computational tools to simulate realistic, full-system operation of lean-burning engines and associated emission control systems.

Simulation tools are essential to engine and vehicle manufacturers working to design emissions systems that meet diesel engine emission goals. They can use the models developed through the DOE effort to analyze their specific systems. Improved models reduce the time and cost needed to develop advanced emission controls and lead to faster implementation of new technologies as they become available.

CLEERS functions as a medium through which researchers share expertise and research results and identify R&D needs. It is co-led by an industry champion and has strong participation from both vehicle and engine manufacturers. Catalyst suppliers became direct CLEERS focus group participants in 2003.

Focus groups have been established for targeted technical exchange, representing each of the three major emissions control technologies—lean NO_x traps, diesel particulate filters, and urea-selective catalyst reduction. CLEERS also has established a web site (www.cleers.org) that includes a large database on research results and another database of publications related to emissions research. Since 2001, CLEERS has held seven workshops to identify the main barriers to success and information gaps for each type of emissions control technology.

FEERC recently received DOE's 2004 Advanced Combustion Engine R&D Special Recognition for its leadership in creating and coordinating CLEERS.

Flame Doctor™ for Ailing Coal Burners

Improving the combustion process in coal-fired power plants, a major source of emissions harmful to human health and the environment, could significantly reduce their harmful effects. However, lacking the technology to monitor individual burners, operators instead have had to rely on global stack data, leading to non-optimal boiler operation with higher emissions and lower efficiency than is actually achieveable. Under the sponsorship of the Electric Power Research Institute (EPRI), ORNL and Babcock & Wilcox have developed a solution to the burner monitoring problem that enables real-time analysis and adjustment of individual burners without the need for installing new instrumentation.

The Flame Doctor continually analyzes the combustion quality of individual coal burners.

The solution is available in the Flame Doctor™ system, a portable hardware and software package for temporary or permanent installation on utility and industrial coal furnaces. The system connects to the existing optical flame scanners on boilers and monitors the status of all burners continuously. Babcock &

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Cleaner Combustion in Diesel Engines

Researchers at ORNL are exploring the potential of new combustion regimes that exhibit simultaneous low emissions of nitrogen oxides (NO_x) and particulate matter (PM). Through proper combustion management, ORNL has greatly reduced NO_x (90%) and PM (30%) without the efficiency penalty typically associated with operating in these regimes. Commonly referred to as high-efficiency clean combustion (HECC), these modes were demonstrated at ORNL on a multi-cylinder engine using only production-like hardware. ORNL's achievement is dramatically different from other approaches to HECC, which often require expensive hardware modifications or result in significant fuel penalties.

Diesel HECC was achieved with a combination of extremely high levels of exhaust gas recirculation and manipulation of fuel injection parameters to lower peak combustion temperatures. Diesel HECC can (a) improve engine efficiency by decreasing heat loss to the cylinder walls and (b) reduce the need for post-combustion emissions controls by lowering engine-out emissions.

The nature of the combustion process is not well understood for most HECC regimes because of incomplete characterization. Many other institutions can characterize the thermodynamics of combustion, but not the details of the combustion products. ORNL researchers have access to powerful analytical methods to characterize the exhaust constituents. The combination of thermodynamic and detailed exhaust chemistry information is expected to dramatically improve the understanding of HECC regimes and result in even cleaner and more efficient oper-

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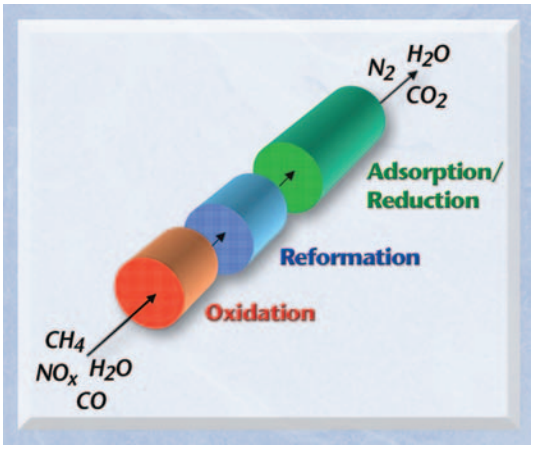
how fuels might be tailored to improve the performance of NO_x aftertreatment systems.

Electricity Generation

FEERC's R&D on electrical power applications for ICEs focuses on the same major goals as its transportation R&D: efficiency, emissions, and costs. Large reciprocating ICEs ("recips") power most distributed energy installations in the United States, and FEERC has ongoing research efforts to improve their performance. Efforts are aimed at improving the efficiency of natural gas recips while reducing their NO_x emissions by developing ultra-lean combustion regimes. Technologies being investigated for ultra-lean operation include a new ignition system based on the rotating arc spark plug developed at FEERC, seeding the air-fuel mixture with hydrogen produced with a natural gas reformer, and advanced control strategies that enable an engine to operate at the edge of the lean limit.

Catalytic processes involved in lean NO_x trap treatment of natural gas engine exhaust.



To improve the efficiency and the emissions performance of large coal-burning power plants, FEERC and two industrial partners have developed a unique instrument called the Flame Doctor™ (see sidebar on p. 3).

FEERC staff also are working with the U.S. military to develop an advanced portable military generator set (gen set). The military needs gen-set systems that are substantially lighter and smaller, more fuel-efficient, logistically simpler to support, and quieter than the conventional ones; require less maintenance; and can withstand the severe environments of military deployments. A proof-of-concept gen-set delivered by FEERC to the military included several advanced technologies and demonstrated that it is feasible for the market to supply the features sought by the military.

For more information on FEERC R&D, see http://feerc.ornl.gov.

Flame Doc. continued from p. 3

Wilcox now licenses the technology from EPRI and offers Flame Doctor as a feature for its coal-fired boiler installations.

The main hardware components are a data acquisition system to collect flame scanner output and a computer for signal processing and display. The scanner signals are analyzed by a diagnostics module, and results are displayed on an interactive graphical user interface (GUI). The heart of the diagnostics module is a set of proprietary algorithms for identifying flame patterns and diagnosing combustion problems. As the scanner signals are processed, Flame Doctor immediately assesses each burner and displays a "flame quality map" on the GUI. The operator can then use the information to adjust burners as needed to optimize performance.

Flame Doctor uses a new approach for discriminating flame patterns: Mathematics derived from chaos theory detect characteristic shifts in each flame's flicker pattern that measure the degree to which that flame has deviated from optimal. Tests show the chaos-based approach to be more discriminating than traditional methods of handling complex optical scanner signals. The data also provide a basis for root-cause analysis that suggests specific reasons for poor performance and specific actions that can be taken for each burner.

The current Flame Doctor system has been demonstrated for coal-fired boilers; the concept should be easily adaptable to oil- and gas-fired burners. Correcting combustion maladjustments could save utilities tens of millions of dollars annually in maintenance and downtime costs and prevent up to 50% of the fuel losses and 30% of the NO_x emissions that result from incomplete combustion.

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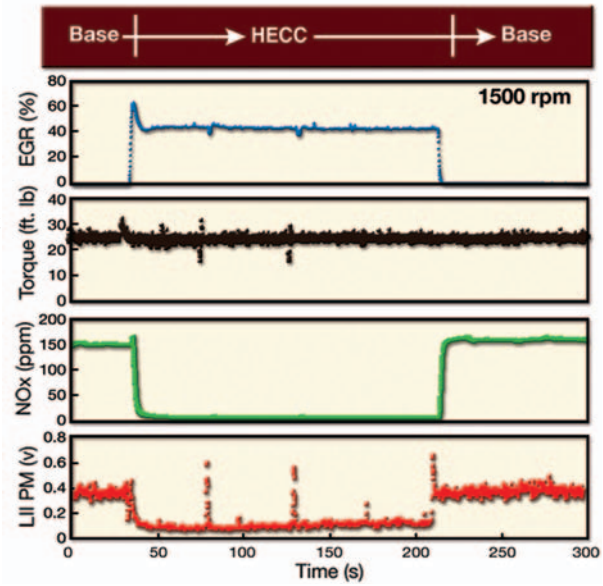
Sponsor: Electric Power Research Institute

Cleaner Combustion continued from p. 3

ation of diesel engines. The data are also being shared with industry and other national labs for the development and validation of improved combustion models and catalysts. Another important aspect of operating diesel engines in advanced combustion modes is the ability to transition in and out of these modes with minimal adverse effects on emissions or performance. ORNL researchers were able to demonstrate seamless transitions into and out of diesel HECC with no significant emissions spikes or effects on performance.



The transition between convential and HECC operation is seamless and does not result in any significant emissions spikes.

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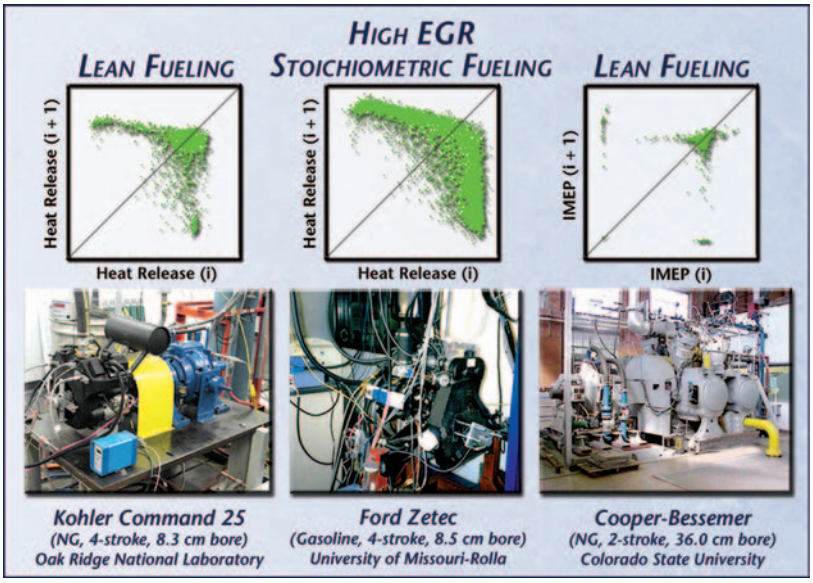
Sponsor: DOE/EERE FreedomCAR and Vehicle Technologies

Lean Clean Smooth Machines: Stabilizing Engine Operation

ORNL researchers are developing control strategies for lean-burn engines (those using more air in the combustion cycle) to stabilize their operation. Potential benefits of the technology include improved engine efficiency, decreased nitrogen oxides emissions, and improved engine stability and durability.

The use of lean-burn engines is a promising pathway toward meeting DOE's goals of low emissions and high efficiency for advanced reciprocating engine systems. However, at lean conditions, combustion efficiency is extremely sensitive to small fluctuations in the amounts of air and fuel inducted into the combustion cylinder. Analyzing these cycle-to-cycle variations can provide reasonably accurate short-term predictions of future combustion behavior.

ORNL was able to implement nonlinear control algorithms in an operating lean-burn natural gas (NG) engine and demonstrate reductions in its cycle-to-cycle variability. This is apparently the first time these techniques have been demonstrated in an NG stationary power engine, and it represents a significant milestone in the development of this technology. Additional algorithm refinement is continuing to reduce cyclic variations.



Although they are different in many aspects, ORNL analysis has shown that these engines exhibit similar patterns of combustion variability that can be controlled to improve energy efficiency.

To demonstrate the usefulness of the technique, ORNL analyzed data supplied by Colorado State University collected from a large-scale NG engine used by the NG pipeline industry. Our analysis of this and other engines indicates underlying similarities in the behavior of all spark-ignition engines operating at dilute fueling conditions, suggesting that they all could be controlled with a similar technique. Engines analyzed to date are shown in the figure.

All three engines exhibit similar patterns of cyclic combustion variation. The similarity of the engine dynamics indicates that similar control strategies could stabilize the combustion of all of these dramatically different engines. Efforts are under way to implement these control strategies in an operating gas compression engine and devise methods for including the technology in NG power generation engines.

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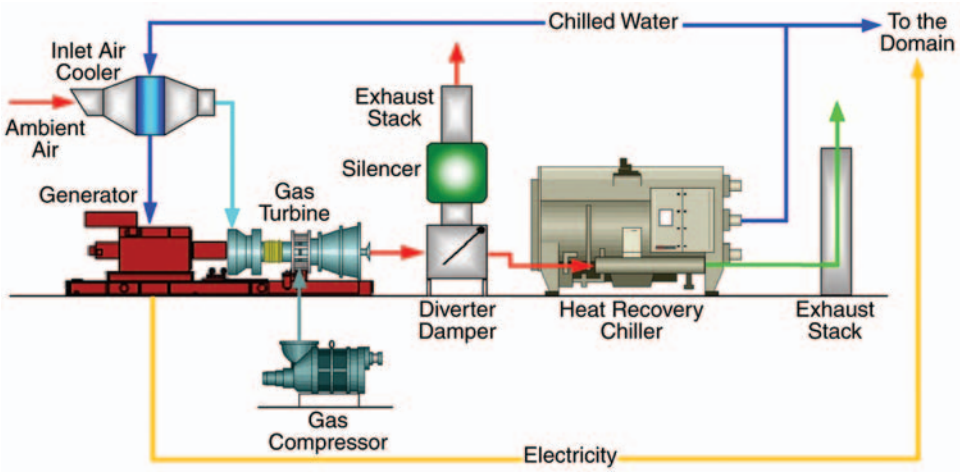
Sponsor: DOE/ EERE Distributed Energy Program

Cooling, Heating, and Power in the Austin City Limits

An integrated energy system (IES) that recently began operating in Austin, Texas, may help revolutionize how businesses power and cool their buildings. It is one of the largest systems in the country combining on-site electricity generation with cooling and heating to save energy while providing a buffer between power users and the electrical grid.



The gas turbine produces electric power, and its exhaust heat powers the chiller.

This prototype energy system was developed through a 2-year partnership between DOE/ORNL and Austin Energy, the local utility. Burns & McDonnell developed, designed, installed, and is testing the IES package, which includes a 4.5-MW gas-fired turbine to generate electricity and an absorption chiller that delivers up to 2500 tons of chilled water.

Electricity produced by the turbine is directed to Austin Energy's utility grid through an on-site substation. The heat exhausted by the turbine (at 900°F) is captured by the absorption chiller to chill water used to cool 1 million ft^2 of building space on the site. Capturing and harnessing waste heat from turbines is an underlying concept for combined cooling, heating, and power (CHP) technologies. The Austin IES expands this concept by

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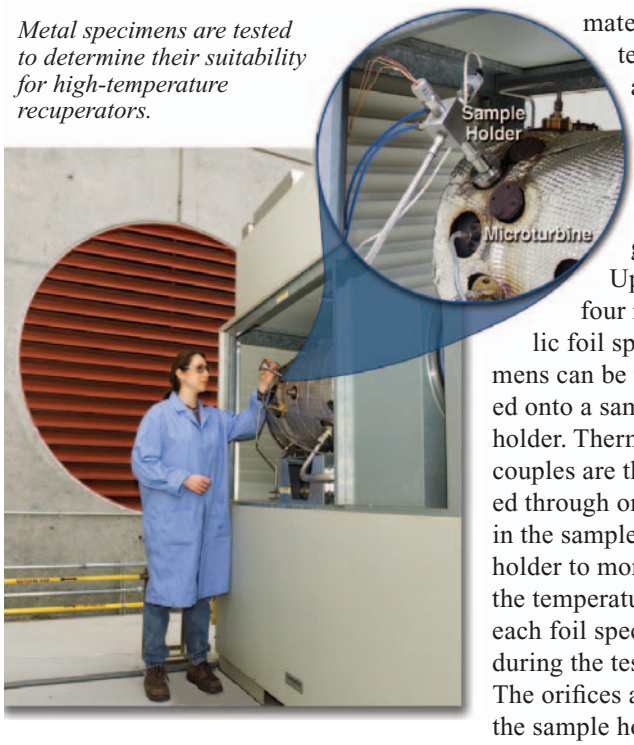
Minimizing Creep and Corrosion in Microturbines

Microturbines, small combustion turbines that generate between 25 and 500 kW, offer several advantages over other small-scale power generation technologies: fewer moving parts, compact size, low weight, reduced emissions, and fuel flexibility. One of the goals of DOE's Microturbine Program is 40% fuel-to-electricity efficiency. Higher efficiency requires higher turbine operating temperatures, and higher temperatures demand improved materials for turbine components.

Turbine efficiency depends largely on the recuperator, which transfers recovered heat from the exhaust stream to the incoming air. Most compact recuperators, used at exhaust temperatures below 650˚C, are made from 300 series stainless steels (e.g., 347). At higher temperatures, these materials are susceptible to creep deformation and oxidation, which cause structural deterioration and leaks, reducing the effectiveness and life of the recuperator.

ORNL's Recuperator Testing Facility is evaluating materials for creep and corrosion resistance to determine which ones are suitable for use in higher-temperature recuperators. A 60-kW microturbine in the facility has been modified to achieve turbine exit temperatures as high as 850˚C. It also has been adapted to allow a sample holder containing test specimens to be placed at the recuperator entrance.

ORNL's test facility is unique in allowing the simultaneous evaluation of three parameters that dictate the durability of candidate materials: temperature, stress and corrosive gases. Up to four metallic foil specimens can be welded onto a sample holder. Thermocouples are threaded through orifices in the sample holder to monitor the temperature of each foil specimen during the test. The orifices allow the sample holder to be pressurized, which allows mechanical stressing of the foils during testing.



Metal specimens are tested to determine their suitability for high-temperature recuperators.

During tests, the sample holder is subjected to a temperature gradient from 630 to 760˚C. Then small test specimens are taken from the foils and characterized by electron microscopy and chemical analysis to identify the mechanisms responsible for degradation of the materials.

Several materials have been evaluated in the recuperator testing facility, including 347 stainless steel, Haynes alloys 230® and 120®, and ORNL modified austenitic steels. ORNL is working closely with microturbine manufacturers to identify the best candidate materials to fabricate the next generation of microturbine recuperators.

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Sponsor: DOE/EERE Distributed Energy Program

Beating the Heat and Humidity

Two U.S. companies are introducing commercial heating, ventilating, and air-conditioning (HVAC) systems incorporating desiccant dehumidification as a result of ongoing research conducted in cooperation with ORNL. The new products will address complex, conflicting cooling, ventilation, humidity control, and energy requirements that challenge modern builders.

The partnership is part of a DOE program that seeks novel high-efficiency technologies to independently control temperature and humidity levels in healthy buildings. The industrial partners are commercializing units that replace and complement existing HVAC hardware alternatives.

One of the private-sector partners, Missouri-based SEMCO, recently introduced an active desiccant–vapor compression hybrid rooftop unit. Another, the Trane Company, expects to have its CDQ™ (Cool, Dry, Quiet) product on the market by 2005. A third partner, the team of Kathabar and AIL Research, is developing a rooftop liquid desiccant system. Field demonstrations for the latter are scheduled for this summer, and commercial production could begin by 2006.

Active dehumidification systems address a key problem in air-conditioning: occupant comfort depends on controlling both sensible heat (temperature) and latent heat (humidity). Because conventional systems do not handle sensible and latent loads separately, they often must overcool humid air to dry it (some systems then reheat the dry air to the desired temperature). Desiccant-based systems pass incoming air through a moisture-absorbing material, usually by forcing it through a wheel with desiccant-coated apertures. Removing the latent load from air before cooling it reduces the amount of energy required for temperature control and allows much more precise humidity control.

The SEMCO and Trane units are similar in size and appearance to conventional packaged rooftop HVAC systems. SEMCO's integrated active desiccant rooftop (IADR) unit can accommodate 0 to 100% outdoor air. It uses natural gas to regenerate (dry) the desiccant material. The Trane CDQ air handler is all-electric and uses return air for regeneration or, for very dry applications, waste heat from the condenser for additional drying. A rooftop CDQ is planned later. Both units combine a desiccant wheel with a conventional cooling coil.

Studies show a large market potential for a packaged rooftop system that provides cost-effective dehumidification and temperature control. More than 85% of commercial buildings in

the United States use packaged HVAC equipment, mostly rooftop units. Those units account for over 85% of the cooling energy used by commercial HVAC equipment. Conventional systems cannot effectively handle the quantities of ventilation air required by modern building codes while maintaining comfortable conditions. In addition, field tests indicate desiccant-based units can significantly reduce cooling energy consumption because they use smaller compressors, run less, and eliminate the need for reheating overcooled air. They also have the potential to reduce strain on the utility grid because the energy savings tend to occur during peak summer electricity demand periods.

ORNL's Advanced Desiccant Systems Program has been working for several years to facilitate the introduction of cost-effective, energy-efficient desiccant-based dehumidification technologies into commercially available HVAC systems. ORNL helped conduct R&D to establish the benefits of active dehumidification, lab-tested system components for manufacturers, field-tested commercially available desiccant-based systems, conducted controlled lab tests of these systems, and is helping develop product ratings and standards.

Trane and SEMCO are introducing HVAC systems that incorporate desiccant dehumidifying technology.

The Cooling, Heating, and Power (CHP) Integration Laboratory at ORNL is testing the IADR as part of an integrated energy system, using waste heat for desiccant regeneration, and will coordinate field testing of the IADR in an Atlanta school. The CDQ is in field tests monitored by ORNL. A liquid desiccant unit, which has the potential to more effectively use waste heat for regeneration, also will be installed and tested in the CHP Integration Lab in 2005.

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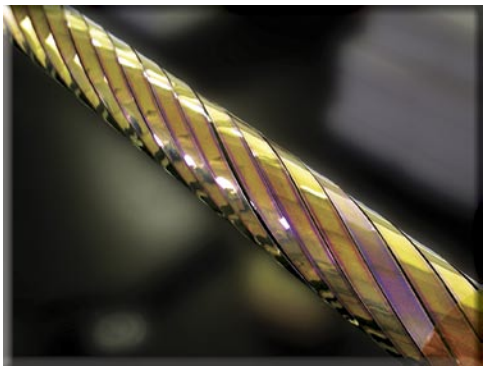
Sponsor: DOE/EERE Distributed Energy Program

ORNL and Partners Test World's First YBCO Power Cable

Ultera and ORNL have jointly designed, built, and tested a 1.25-m-long prototype high-temperature superconducting (HTS) power cable made from 1-cm-wide, second-generation conductor tapes. The tapes, manufactured by American Superconductor Corporation (AMSC), are coated with yttrium-barium-copper oxide (YBCO).



Close-up of the cable showing 1-cm wide YBCO tapes.

ORNL researchers originally developed the technology for fabricating the superconducting tape, which was subsequently licensed by AMSC. The tape has a 75-μm-thick substrate made from a nickel-tungsten alloy, a 1-μm-thick YBCO layer, and 50 μm of copper stabilizer, for a total thickness of about 150 μm. The HTS layer is approximately in the center of the tape cross-section. The two-layer cable was built by Ultera; each layer had twelve 1-cm-wide YBCO tapes wound on a 43-mm-diameter form.

AMSC's second-generation superconducting tape was robust enough to be shipped to Ultera, stored, handled, manufactured into a cable, shipped again to ORNL, and tied into some fairly massive copper cable connections.

Electrical tests of the cable were performed in liquid nitrogen at 77 K. The dc testing included determination of the V-I curve, with a critical current of 4200 A. This was consistent with the properties of the 24 individual YBCO tapes. The ac testing was conducted at practical current levels of up to 2500 A_{rms}. The ac losses were measured calorimetrically and electrically. Losses of about 2 W/m were measured at a cable ac current of 2000 A_{rms}.

Over-current testing was conducted at peak current values of up to 12 kA for pulse lengths in the range of 0.1–0.2 seconds. The cable temperature increased to 105 K for a 12-kA, 0.2-second over-current pulse, but the cable showed no degradation after the sequence of over-current testing. This commercial-grade HTS prototype cable demonstrated the feasibility of second-generation YBCO tapes in an ac cable application. The next step is to make longer HTS cables (5–100s of meters) using YBCO coated-conductor tapes with full-scale cable terminations rated for high voltage (15–138 kV).

The work on the YBCO cable was done under a cooperative agreement between Southwire Company and ORNL.

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Sponsor: DOE Office of Electric Transmission and Distribution

The complete, instrumented 1.25-m YBCO cable ready for testing. The massive copper end connections for the external copper cables are on each end.

Financing to Launch GHPs and CHP

DOE's Federal Energy Management Program (FEMP) has contributed significantly to national energy savings through alternative financing mechanisms and by taking technologies such as geothermal heat pump (GHP) and combined heat and power (CHP) systems to federal facilities nationwide. ORNL has helped establish and streamline approaches to alternative financing and has provided technical leadership in GHP and CHP technologies for FEMP. As a result, the total investment value of federal GHP projects in the last 2 years (~$70M/year) exceeds the total for the previous decade.

GHP retrofits for military family housing like this account for much of the federal investment in GHPs, more than $200 million to date.

DOE has recognized ORNL's GHP program as a Best Practice model for technology transfer. ORNL's GHP team supported the competitive procurement to place technology-specific GHP super energy savings performance contracts (ESPCs), provided technical assistance on the pay-from-savings projects developed by the private energy service companies (ESCOs), and performed the necessary applications R&D. ORNL has proved that super ESPCs are a potent tool for technology transfer and deployment.

ORNL is also addressing technical and financial barriers to the use of CHP at federal agencies. As a result of terrorist activities and the problems created by a massive power blackout in 2003, FEMP has expanded its mission to include energy security. Efficient on-site or near-site power generation through distributed CHP is viewed as an important part of energy security.

ORNL screens federal sites for CHP opportunities and provides follow-on technical assistance to keep projects moving forward. Through FY 2003 ORNL has completed

- 141 site screenings for CHP potential
- 49 technical reviews (e.g., for proposals that agencies receive from private project developers)
- 32 in-depth CHP feasibility analyses

Through these efforts, ORNL has identified 117 potential CHP projects worthy of follow-up and is working with DOE regional offices to educate federal agencies on their options. This activity provides opportunities to demonstrate advanced technologies emerging from EERE's Distributed Energy Office. Federal sites are hosting integrated systems from two of the office's seven "packaged CHP industrial teams."

Of the last 126 MW of federal CHP projects awarded, over 90% of the capacity was alternatively financed. ORNL determined that over 70% of the 1600 MW of federal CHP potential resides in either the Department of Defense or Veteran's Affairs. These agencies sometimes prefer CHP projects developed and financed under property management authorities (often referred to as enhanced use leasing or EUL). Unlike ESPC, which results in improvements to government-owned facilities, EUL involves out-leasing property to a private developer that builds, owns, and operates the CHP plant and sells energy products (electricity, steam, chilled water) back to the agency and sometimes other customers.

ORNL is working to improve the financial vehicles available to agencies. It analyzed super-ESPC data provided by FEMP to determine areas where agencies could receive substantial cost savings and identified an improved financing approach projected to save taxpayers $400 to 800 million over the next 10 years. Lower-cost financing means new EERE technologies will be feasible in more ESPC projects. The guarantees in ESPCs help mitigate customers' concerns about the reliability of new technologies. Since direct funding is often not available for projects, agencies have benefited greatly from the alternative financing vehicles.

For more information, see www.ornl.gov/sci/femp/index.shtml and www.eere.energy.gov/femp/

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Sponsor: DOE/EERE Federal Energy Management Program

After installation, there is little visible evidence of a GHP system.

ORNL's FEMP team has been tapped to assist military installations in the Southeast in developing energy security plans required by U.S. Army headquarters. ORNL is working with Ft. Bragg, NC, to develop its energy security plan, which will serve as a model to help the other 15 Southeastern installations develop their plans.

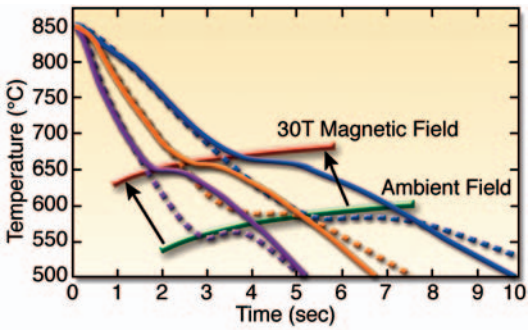
Ft. Bragg is already implementing several key aspects of the plan, including installing packaged CHP systems and consolidating energy loads to a micro-grid that can stand alone if the regular utility grid fails. An important part of that microgrid will soon be operating. ORNL is part of a team led by Honeywell that is developing a 5-MW packaged CHP system prototype for Ft. Bragg that soon will be installed.

ORNL is also testing its SensorNet system—which provides early warning of the presence of airborne or waterborne hazards—at Ft. Bragg as part of the base's "total installation awareness" program. Energy and water utility systems are among several being integrated into the installation security monitoring and response effort. Ft. Bragg is a key partner with ORNL and FEMP and is recognized as a leader in energy security practices.

Magnetic Field Processing for Designer Materials

A new processing methodology being developed at ORNL will enable the production of a new class of materials with novel microstructures and superior properties and optimize the processing of conventional materials. The new method, which involves applying a strong magnetic field as an alloy cools, enhances phase transformation kinetics for several ferrous alloys. It will allow materials with enhanced performance to be made with shorter heat-treating cycles, reducing fabrication costs and energy consumption for industry.

In ferrous materials, the final microstructure is determined by phase transformations that occur when the material is cooled from a high temperature to a ferromagnetic phase. Applying a strong magnetic field facilitates the formation of the ferromagnetic phase to enable the transformations to occur at higher temperatures and accelerated rates.



Temperature changes over time for 1045 stainless steel cooled at three different rates with (solid lines) and without (dashed lines) a 30-T magnetic field. Transformation occurs more rapidly and at higher temperatures in the magnetic field.

A novel application of this technology is magnetic field processing control of the ferrite phase volume fraction during cooling of an alloy steel. Cooling under a high magnetic field increases the ferrite volume fraction significantly, creating a microstructure that should be easier to machine than conventional steel. The results translate to higher production rates and longer tooling life.

To date, sample sizes for experiments have been limited by the use of a 32-mm-diameter magnet. Future experiments will be conducted with a 195-mm-diameter magnet with a maximum 20-T field (a ~30-T field is currently in use). Larger samples are needed to characterize the effect on properties such as yield strength and fatigue life, and limiting field strength to less than 20 T is in line with current superconducting magnet technology. Industrial use of the technology likely will require superconducting magnets because they are easier to use and more energy-efficient.

A patent application has been filed for the technology. The research results are being discussed with several potential industrial partners for applications including the development of higher-strength, higher-toughness steels and bulk nanocrystalline ferromagnetic materials. Meetings have been held at ORNL with various industries interested in this breakthrough technology, including cast iron, heat treating, and steel companies.

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Sponsor: DOE/EERE Industrial Technologies Program

Supply Chain Tools Aid Bio-based Businesses

A biobased energy enterprise depends upon a secure supply of biomass material (e.g., corn stover) to operate successfully. The feedstock supplier expects to make a profit with minimal damage to the soil or the environment, and the user expects an adequate, secure supply that is cost-competitive and of uniform quality. A solution to these often opposing expectations requires complex modeling tools to develop optimum supply chain systems and operations.

ORNL's feedstock modelers are helping to simulate biomass supply-chain options to enable the reliable delivery of biomass feedstocks to a biorefinery at a delivered cost of $35/ton dry weight. The models also guide research on supply-chain components (i.e., approaches to collecting, handling, storing, and transporting biomass feedstocks). By developing and applying engineering cost analysis models and enterprise-level simulations of supply logistics, ORNL is investigating how climatic, geographical, and operational constraints affect the availability of biomass from the field to the biorefinery. The models also quantify the allocation of resources (labor, equipment and structures), the environmental impact of handling and storing large quantities of biomass, and the net energy flow for a biomass operation.

In collaboration with the Universities of Tennessee and Kentucky, ORNL has collected field data on the operational performance of corn stover harvesting and the field characteristics of stover since 2001. Limited data are also now available to relate the maturity of corn kernels to moisture in stover stalks so that the timing of the grain and stover harvest can be optimized to enable the best use of labor and field equipment.

ORNL scientists have completed the necessary framework for the supply logistics model. A series of equations representing various field operations, storage, and transport systems has been developed, and solutions to the equations have been coded using a commercially available simulation language. The model is being tested on a number of new harvest and supply scenarios, including single-step and selective harvest systems and bulk storage operations. The next step is to verify the model performance using data from commercial operations.

ORNL and its university partners are collecting field data on corn stover harvesting for use in computer models of biomass operations.

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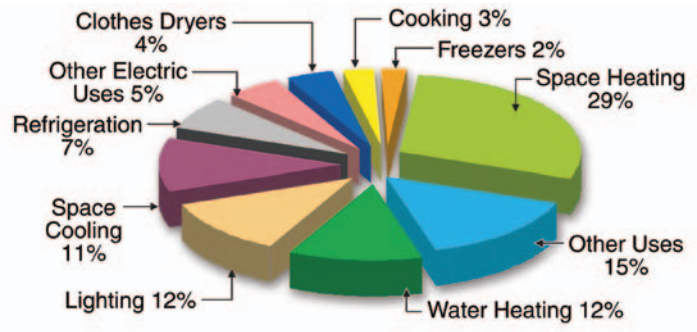
Sponsor: DOE/EERE Biomass Program

ORNL's EERE Program... "In Hot Water"

Scientists at ORNL's Buildings Technology Center are investigating the second-largest energy use in residential buildings—water heating. Through energy efficiency and infrastructure improvements, researchers hope to reduce energy use and energy bills.

Specific areas of study include

- Water heating dehumidifier (technical lead: Evelyn Baskin, baskine@ornl.gov)
- Hot water distribution system (technical lead: Bob Wendt, wendtrl@ornl.gov)
- Heating water with waste heat (technical lead: Jeff Christian, christianje@ornl.gov)
- Heat pump water heater (technical lead: John Tomlinson, tomlinsonjj@ornl.gov).



Water heating accounts for 12% of the energy used in residential buildings (2003 data).

Water Heating Dehumidifier

Humidity control is an issue for tightly insulated new houses, which often must bring in humid outside air to meet fresh air requirements. Building on their experience with the energy-efficient residential heat pump water heater (HPWH), ORNL researchers have designed an appliance that combines HPWH technology with dedicated dehumidification—the water heating dehumidifier (WHD). It was recently selected by the Education and Research Consortium of the Western Carolinas to be developed, produced, and marketed.

The WHD consists of a compressor, two condensers, an evaporator, and an expansion device. The second air-cooled condenser is used when the WHD operates in dehumidification-only mode. Several water heating condenser options will be studied in the development effort, including a submerged unit that provides enough surface area within the tank to heat the water, and a surface-mounted unit attached to the tank bottom. The estimated retail cost for a WHD is about $400–600. In comparison, a 30-pint dehumidifier (typically adequate for a 1600-ft^2 area over 24 hours) costs about $160, a 65-pint dehumidifier about $250, and a standard 40- to 50-gal electric water heater about $200 or $300. The WHD goal is the Energy Star® criterion of an Energy Factor of at least 1.2 for a dehumidifier that removes 10–24 liters of water from the air daily.

Modeling and lab tests of several configurations will provide data for selection of a design for a marketable, low-cost, energy-efficient WHD. A coordinated market assessment activity with Clemson University and ORNL is providing additional design input.

By the end of CY 2004, two working prototypes will have been built by Carolina Stamping Company and tested at Asheville-Buncombe Technical College. Following design refinement, units will be tested under controlled conditions at ORNL. Plans for 2005 call for construction of 10 or more WHD packages for field testing in North Carolina homes and at ORNL, and other actions leading to early commercialization.

Heating Water With Waste Heat

ORNL designed, helped build, and is analyzing energy data from a Habitat for Humanity house with near-net-zero energy use that is equipped with integrated heating, cooling, and appliance technologies to maximize energy savings.

Enviromaster International provided a HPWH for the house that is integrated with the refrigerator, the unvented crawl space, and the heating and cooling system. Waste heat from those sources is used to pre-heat the water in the HPWH. The waste heat source varies, depending on whether the space heat pump is set for heating or cooling mode. In cooling mode, motorized dampers direct the warm air from behind the refrigerator into the HPWH closet for use by the HPWH evaporator. The cooled air exhausted from the HPWH evaporator is then directed back into the kitchen to help air-condition the house. In heating mode, fans pull air from the crawlspace, direct it to the HPWH evaporator, and then exhaust it outside the house.

Integration of multiple waste heat streams can greatly improve the efficiency of water heating. The COPs for the HPWH have ranged from 2.0 to 2.2 throughout the year.

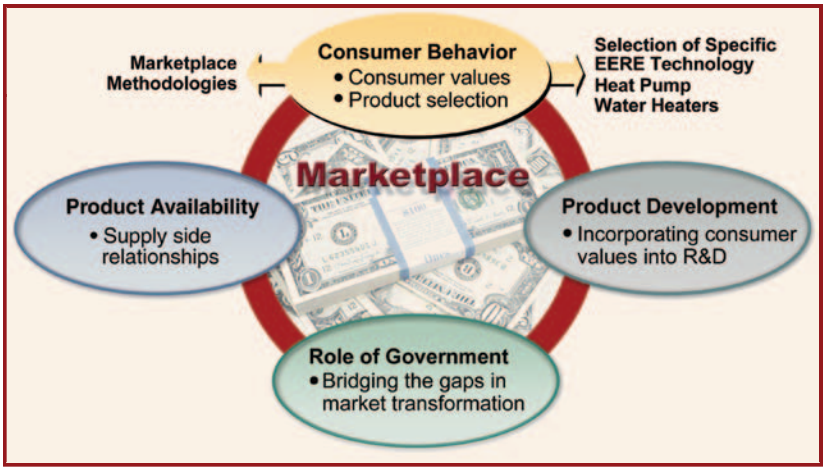
The heat pump water heater uses waste heat from other appliances to preheat water.

Hot Water Distribution System

The goal of the hot water distribution project, sponsored by the California Energy Commission, is to evaluate the energy and water performance, economics,

and barriers to use of advanced domestic hot water distribution systems in California residences.

A numerical model was used to estimate heat loss or gain from insulated and non-insulated hot water pipes, which affects energy use, water consumption, and waiting time at use points. The model permitted evaluation of several alternatives (>250 scenarios). The results provided the following conclusions.



An understanding of how consumer values influence buying decisions is essential to successful market penetration.

Continuous recirculation systems cost substantially more to build and operate and waste more energy than any other system. Therefore, although they minimize water waste and wait times for hot water, they are not recommended.

Adding a demand recirculation pump and controls increases conventional system costs by about $600 but reduces operating cost, waste, and wait times. Wait times are similar to those for continuous recirculation systems, and water and energy waste are much less than with conventional systems. Demand recirculation systems can be installed in both new and existing housing.

It is crucial to understand consumer values and willingness to pay for features and to recognize how they influence purchase decisions.

For the segment of the new construction market that is sensitive to first cost (i.e., most production homes), centrally locating the water heater cuts wait times and waste for a modest cost increment.

Parallel pipe distribution systems offer an attractive alternative for some house designs. They are less costly to install than conventional systems and may reduce wait times; however, their energy and water savings are sensitive to hot water use patterns. When the model assumes clustered hot water draws, parallel pipe systems compare to conventional systems with regard to water and energy use and waste. When a cold-start pattern is modeled, they outperform conventional systems.

Heat Pump Water Heater

ORNL won a 2001 R&D 100 award for a "drop-in" residential HPWH, developed in partnership with industry, that is three times as energy-efficient as the best conventional electric water heater. The key to its efficiency is a small heat pump on the top of the water tank that extracts heat from the surrounding air. As a side benefit, the HPWH can provide cool, dehumidified air in the space where it is installed.

A recent market study conducted by ORNL and co-sponsored by DOE and the New York State Energy Research and Development Agency found that although it has met technical goals and has been on the market for 20 years, the HPWH has had virtually no impact on water heating. In some cases, HPWH reliability and quality control are well below market expectations; early units developed a reputation for poor reliability compared with conventional water heaters. In addition, HPWH first costs may be three to five times higher than for conventional units.

For practical purposes, research shows consumers don't care how water is heated but focus on attributes such as initial and operating costs, performance (e.g., meeting product claims), serviceability, and size. Thus the principal drivers for penetrating consumer markets are demonstrating reliability, leveraging the HPWH's dehumidification capability, and creating programs that embrace life-cycle cost principles. Its marketers also need to implement a product warranty with scrupulous quality control, reduce the first price through engineering, and court niche markets.

Understanding consumer values and willingness to pay for product attributes and recognizing how they influence purchase decisions are crucial. Continued market research at ORNL is focused on incorporating market knowledge into the R&D process while building in continuous dialogue between market research and the R&D programs. Partnerships among stakeholders to gather consumer feedback and market analysis while conducting R&D will facilitate a strong framework for successful market penetration of energy-efficient technologies.

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News Briefs

Marilyn Brown is Anderson Medal Winner

Marilyn Brown, Director of the EERE Program at ORNL, has been awarded the 2004 James R. Anderson Medal of Applied Geography. Brown is a national leader in the analysis and interpretation of energy futures in the United States. An ORNL researcher for 20 years, she is the first social scientist to direct ORNL's largest program office.

Advanced Heating System Is R&D 100 Winner

Among the 2004 R&D 100 awards for 2004 is the "advanced heating system for high-performance aluminum forgings" developed by several ORNL researchers and their industrial partners. The system uses a combination of radiant and convective heating for materials processing. It reduces the heating time and energy required for heating aluminum billets and produces high-performance forgings with properties superior to those resulting from conventional techniques. The R&D 100 awards are presented annually to recognize the year's most significant technological innovations.

Award winners (l to r): Greg Engleman, Jackie Mayotte, Randy Howell, Craig Blue, Vinod Sikka, Evan Ohriner, and Puja Kadolkar.

Paranthaman is Journal Editor

Parans Paranthaman of ORNL has been named an associate editor for the *Journal of the American Ceramic Society*, the premier forum for original research in ceramics. Paranthaman is a senior researcher whose work is sponsored by the Office of Electric Transmission and Distribution–Superconductivity Program for Electric Power. He is a past winner of an R&D 100 award for co-inventing the RABiTS technology.

Austin City Limits continued from p.5

using the turbine exhaust alone—with no supplemental power—to fuel the world's largest exhaust-fired absorption chiller. The system is designed so that the waste heat output closely matches the chiller capacity. It is expected to operate at 70–80% efficiency, compared with 55% efficiency in the best central power plants.

Packaging CHP equipment into IESs makes the technology easier to use and more cost-effective. Packaged IESs cut CHP capital costs by 15 to 30% and reduce installation time by using skid-mounted construction modules.

The Austin IES is one of six DOE IES demonstration projects being conducted nationwide to develop and expand the use of packaged CHP systems. It will be monitored and tested by the ORNL-Austin Energy-Burns & McDonnell team and the University of Texas at Austin. Field data will be acquired for 2 years and used to model system performance—providing ample opportunities for replication.

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Sponsor: DOE/EERE Distributed Energy Program

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