Science & Technology HIGHLIGHTS

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PV Demo Helps Move Solar Roofs into the Mainstream

A field study at the Buildings Technology Center at ORNL will address several issues associated with the integration of photovoltaic (PV) technology into roofs. The field study and distributed energy resources (DER) demonstration is a cooperative effort with the Tennessee Valley Authority, BP Solar, the Federal Energy Management Program, and the ORNL State Partnership Program in conjunction with the State Energy Office of Tennessee.

PV equipment makers want to know how the conversion of sunlight to electricity (instead of heat) and shading of the roof by PV arrays impact a building's cooling load. They also need validated data on how weathering affects the power output of their PV modules. TVA needs experience in integrating PV technology into the building envelope and enabling solar-powered buildings to transmit surplus power to the utility grid.

BTC researchers will develop a rating procedure to compare the energy efficiency of a roof that integrates PV equipment with the efficiency of a conventional insulated roof. Previous roofing research at the BTC has provided 3 years of temperature and heat flow data for just about every material used in low-slope commercial roofing. Those data will be used to quantify and map the shading effect of offset-mounted PV arrays on the R-values of 10 different roofing systems.

Exposure to ultraviolet light yellows solar panels, decreasing their solar reflectance. Reduced reflectance results in higher temperatures, which lower the conversion efficiency of PV semiconductors. The BTC's research will document the performance of BP's solar modules and determine the factors that affect their performance.

The PV arrays integrated into the building are expected to supply 8.5 kW of energy to the utility grid. The project will evaluate the performance of the PV DER power storage systems employed and provide lessons for TVA and other utilities in deploying and integrating DER technologies.

A particularly valuable aspect of the demonstration is its educational benefit. It will provide TVA, state agencies, the solar industry, and the public with performance data for building-integrated photovoltaic (BIPV) technology, which can mitigate building electrical loads and make PV more economically attractive. In 10 years, PV has dropped from an installed cost of about $20/Watt to about $5/Watt. A cost of $3/Watt would make PV about even with coal and gas power generation. BIPV may prove to be a good option for supplementing utility resources in warmer climates.

Bill Miller (top) and Jerry Atchley examine solar PV panels under study at the BTC.

Demonstrations of emerging technologies are a key step toward moving R&D into the marketplace. DOE encourages the use of ORNL facilities as test beds for demonstrating advanced energy technologies. The PV-DER study is a good example of such projects, as are the fuel cell monitoring effort at the BTC (p. 9) and an internet monitoring/control system for a geothermal heat pump installation (p. 3). See the box on this page for a list of other demonstration projects under way at ORNL.

For more information about research at the BTC, see www.ornl.gov/btc

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Sponsors: Federal Energy Management Program, TVA, ORNL State Partnership Program, Tennessee State Energy Office

Recent Demonstration Projects at ORNL Facilities

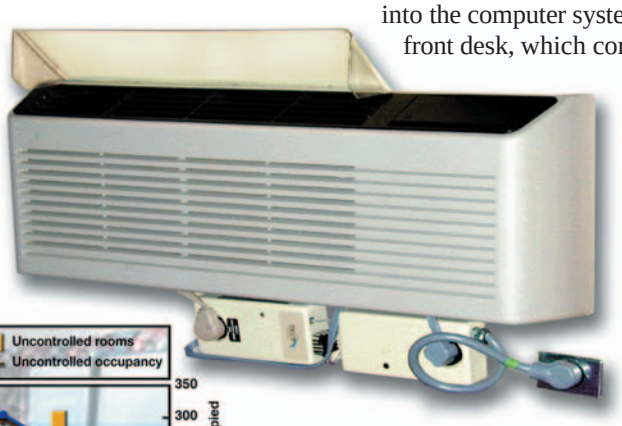
- First LED traffic light in the state of Tennessee
- First residential PEM fuel cell operating in the Southeast
- Microturbines supplying power (with waste heat recovery) to several labs
- 200-kW fuel cell supplying power to National Transportation Research Center
- Photovoltaics demonstration at the Buildings Technology Center
- Caterpillar natural gas engine/generator system to demonstrate new technologies for the Advanced Reciprocating Engine System program
- Fleet of 40 E85-fueled vehicles and an 8,000-gallon tank supplied with locally-produced ethanol

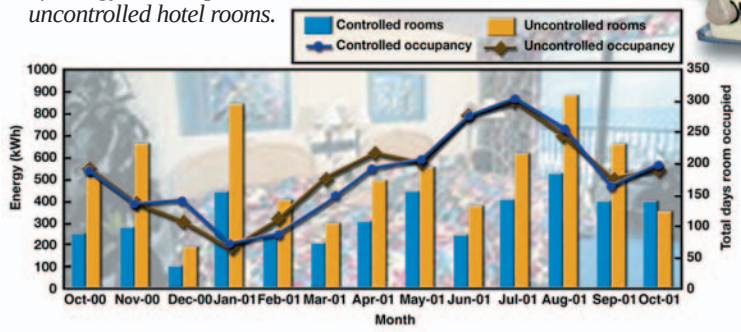
ORNL Confirms Energy Savings from Digital HVAC Controllers

Heating, ventilation, and air-conditioning (HVAC) systems consume about a third of the electricity used by the lodging industry. Devices are available to regulate the power demand of HVAC units in hotels and motels, but independent performance data are lacking. To fill the gap, ORNL conducted a field study of an HVAC supervisory control device in a hotel in Pigeon Forge, Tennessee.

Testing by Phillips Electronics indicates the devices could save 50–80% of the energy used in unoccupied rooms. ORNL's study assessed those estimates and identified the impacts of the technology on room comfort conditions.

The yearlong field study began in September 2000. A total of 163 Digi-Log controllers were installed; 12 rooms with controllers and 12 rooms without them were monitored. Data were downloaded nightly via a modem inside a data acquisition system on each monitored unit.





Right: *Air-conditioning unit with controller (left under unit) and ORNL data acquisition system (right under unit).* Below: *Comparison of energy consumption in controlled and uncontrolled hotel rooms.*

The controller is a plug-in device installed between an HVAC unit and its electrical outlet. As guests check into or out of a controlled room, the desk clerk enters the occupancy status into the computer system at the front desk, which communicates with the controller. The controllers are programmed to maintain temperatures within established parameters for occupied and unoccupied rooms.

The data showed rooms using the power controllers consistently saved energy. During the test, in occupied rooms, controlled HVAC units consumed 32% less energy than uncontrolled units. In unoccupied rooms, controlled units used 43% less energy than uncontrolled units.

Temperature and relative humidity in uncontrolled rooms ranged between 68 and 80°F and 40 and 70%, respectively. In controlled rooms, temperatures ranged from 69 to 80°F and

continued on page 12

Frostless Heat Pump Ready for Home Testing

The frostless heat pump is an advanced heat pump technology developed at ORNL that reduces frosting of the outdoor heat pump coil, improving the efficiency of the unit and the comfort level of building occupants.

Development of a frostless heat pump demonstration unit was completed in 1999 by researchers at ORNL's Buildings Technology Center. *R&D Magazine* gave the new technology one of its coveted R&D 100 awards for that year. Since then, the technology has been field-tested and is being pursued by Amana Heating and Air-Conditioning.

To make the frostless heat pump commercially viable, the design and placement of the accumulator heater and the operation of the heater control system were refined. The heat pump must be as efficient as possible, maintain a high level of indoor comfort, and eliminate all possibility of overheating the refrigerant and damaging the compressor.

Amana has built several frostless heat pump demonstration units at its Fayetteville, Tennessee, plant. Those units are being installed in homes for testing. Two of the units have been made available to the Tennessee Valley Authority (TVA) for installation and monitoring in dwellings. ORNL is helping develop the instrumentation for TVA's monitoring and analysis.

Joe Kilpatrick of TVA (left) and Ron Domitrovic of ORNL check out a frostless heat pump.

So far, the technology is performing beyond TVA's expectations, said Joe Kilpatrick of TVA's Public Power Institute.

The team is currently working to redesign the accumulator heating element to reduce its manufacturing cost. "We are trying to eliminate as much drilling and welding as possible to make it simpler and cheaper to manufacture," said ORNL's Vince Mei. ORNL will test the improved heating element during the 2002/2003 heating season.

Amana hopes to make frostless heat pumps available to consumers in the next year or two.

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Sponsors: TVA, DOE/EERE Building Technologies Program

Internet-Controlled GHP Brings Technology to the Classroom

ORNL researchers have developed an internet-based real-time monitoring and control system for use with a geothermal heat pump (GHP) installed at a school in Oak Ridge, Tennessee. The system monitors conditions inside classrooms and will be used for remote, web-based control of the climate control system.

The 4-ton ground-coupled water-source GHP was installed at Robertsville Middle School in summer 2001. It incorporates a fresh air enthalpy exchange system designed to minimize the humidity load on the GHP while maintaining the fresh air flow recommended by the American Society of Heating, Refrigerating and Air-conditioning Engineers—15 cfm per person.

The Tennessee Valley Authority funded the earthwork for the project and conducted a ground conductivity test.

ORNL developed the web-based system to track climate and air quality conditions in a classroom conditioned by the GHP and in a baseline classroom on a conventional heating/cooling system. Carbon dioxide concentrations in the classrooms are monitored to track the amount of fresh air needed to maintain acceptable air quality. Sensors installed in the classrooms provide a constant stream of data to the monitoring system. In addition to the real-time monitoring, the system stores data for further analysis. The monitoring system uses standard commercial components, but ORNL researchers developed the control algorithms being used.

Through the heating season, only passive monitoring was conducted while the system was fine-tuned. In June, an online control system replaced the conventional thermostat controlling the GHP. It will allow remote, web-based control of the GHP with customized access and control. For instance, classroom occupants could be allowed control of the temperature set-point within a certain band, but control of fan and damper settings and weekly schedules could be limited to the physical plant.

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Sponsor: Tennessee Valley Authority and ORNL's State Partnerships Program

The GHP at the Robertsville school removes heat via a water/glycol solution pumped through these vertical wells bored in the earth just outside the classroom.

Big bad wolf, take note . . .

Aircraft Exhaust Substitutes for Gale-Force Wind in Experiment

Is backing an airplane up to a house and cranking it up an effective way to evaluate what happens to a house in a high wind? If so, it would be a lot more timely for researchers than waiting around for a hurricane or tornado.

A C-130 transport plane prepares to "blast" a manufactured house.

Researchers from ORNL's Buildings Technology Center, along with colleagues from Texas Tech University and the Florida Solar Energy Center, addressed that issue in an experiment on a closed Air Force base in Texas. They wanted to determine whether a methodology could be developed to use a large aircraft to generate hurricane-level winds to test the airtightness and durability of residential buildings after exposure to severe winds, explained Andre Desjarlais of ORNL.

The test case was a previously owned 15 × 50 ft 2000-model single-wide manufactured house installed by the research team near a runway on the base. To characterize air infiltration in the house before the wind event, blower door and duct tests were performed. An infrared survey also was conducted to identify any areas of unusual air leakage.

Turboprop exhaust from a C-130 transport plane was the "wind." The aircraft was repositioned at scheduled intervals to direct the powerful exhaust at the front and the end of the dwelling. Wind was applied in bursts of 40, 50, 60, 90, and 100 mph, the speed of each test monitored by wind velocity transmitters.

After the wind tests were completed, air infiltration into the house was measured again. The data showed no apparent change in the airtightness of the house after the wind exposure, even though there was some marginal damage to the structure.

The project proved the feasibility of the experimental methodology. The ORNL researchers would like to test another manufactured home, a site-built house, and a modular home following the protocol established in these tests.

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Sponsor: DOE/EERE Building Technologies Program and the National Institute for Standards and Technology

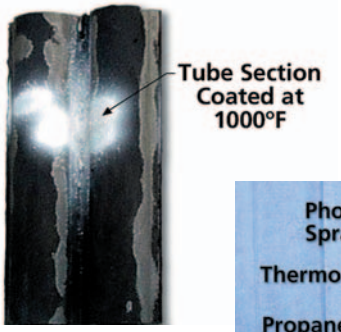
Phosphor Thermometry Diagnoses Feverish Boiler Tubes

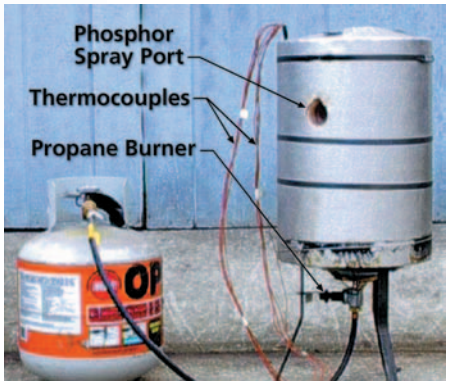
Boiler tubes in steam power plants operate under extreme temperatures and pressures that can cause them to fail, endangering lives and disrupting operations. Researchers at ORNL and Tennessee Technological University (TTU) have developed a way to measure boiler tube temperatures during operation to spot problems before they become critical.

The technique, phosphor thermometry, involves coating a surface with a temperature-sensitive phosphor, using a light source (such as a laser) to cause the phosphor to fluoresce, and then determining the surface temperature by analyzing the fluorescence. (ORNL developed this technique for the steel industry and received an R&D 100 award for the technology, along with its industrial partner National Steel.)

A "hot spot" on a boiler tube surface indicates impaired steam flow through the tube. A damaged tube deteriorates rapidly. If a leak develops, the resulting steam jet may cut other nearby tubes, starting a cascade that will knock the boiler offline and risk injury or death to workers. Accurate thermometry can signal that a tube needs repair before it fails.

TTU developed an optical probe to be installed in an access port in a furnace to monitor the temperature of a phosphor-coated surface. Next, an application system was needed to coat a boiler tube during operation. ORNL developed a promising coating mixture (a magnesium-based phosphor, mixed with binders) and sprayer (a modified Walther Pilot spray gun). In tests at TTU, the system successfully applied a strong, uniform coating to a tube operating at more than 1000°F. With successful coating application demonstrated, the phosphor thermometry system is ready for field testing. ORNL and TTU are contacting organizations that might be interested in testing the system.





Left: *Boiler tube section with deposited phosphor.* Below: *High-temperature phosphor deposition test rig.*

The capability to accurately measure and adjust boiler tube surface temperatures in operation would increase plant efficiency and availability, saving millions of dollars and improving energy efficiency.

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Sponsor: ORNL State Partnerships Program

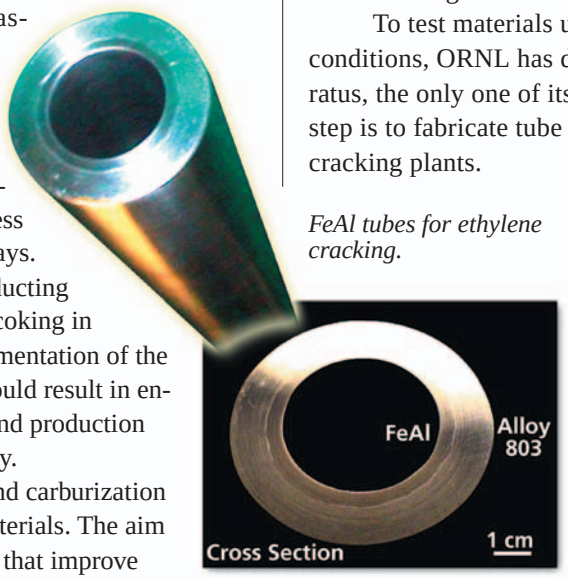
ORNL Materials Retard Coking in Ethylene Cracking Furnaces

Cracking furnaces produce ethylene by subjecting petroleum to extremely high temperatures. The harsh temperatures in the furnaces cause coke formation inside the stainless steel furnace tubes and carburization of the tube walls. Coking reduces ethylene flow in the tubes and hinders heat transfer across tube walls, increasing energy consumption and reducing productivity; and carburization shortens the life of the tubes. Periodically (about every one to two months), the furnaces must be shut down and "decoked" by heating the tubes to 1040˚C or higher, a process that takes from several hours to several days.

ORNL materials scientists are conducting research aimed at dramatically reducing coking in ethylene furnace tubes. Successful implementation of the technology, industry analysts estimate, could result in energy savings of more than a trillion Btu and production cost savings of over $500 million annually.

ORNL is addressing both coking and carburization through the development of advanced materials. The aim is to develop tubes of advanced materials that improve tube performance by an order of magnitude over the materials currently used. Two ORNL-developed alloys have been identified that can improve coking resistance by an order of magnitude, and a processing technology has been developed to fabricate bimetallic tubes using the two alloys in combination with stainless steel.

To test materials under simulated ethylene production conditions, ORNL has developed a flow-through coking apparatus, the only one of its kind in the United States. The next step is to fabricate tube sections and install them in ethylene cracking plants.



FeAl tubes for ethylene cracking.

Partners in the project include several chemical, oil, and materials companies. The chemical industry partners are assisting with the industrial trials, and materials producers are involved in the pilot-scale fabrication trials.

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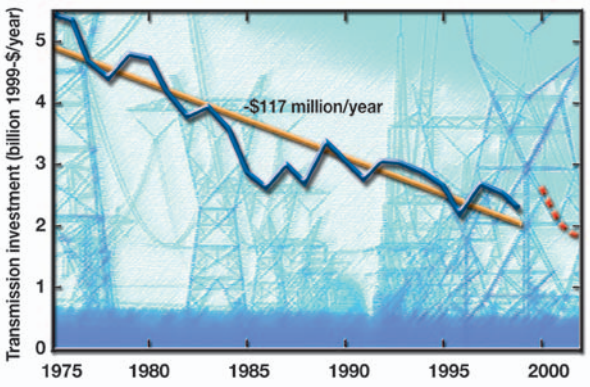
Sponsor: DOE/EERE Industrial Technologies Program

Transmission Study Highlights Congested Power Superhighway

The National Energy Policy directs the Secretary of Energy to examine the benefits of establishing a national electrical grid and to identify major transmission bottlenecks and ways to remove them. In response, DOE conducted a National Transmission Grid Study (NTGS) to examine issues resulting from transmission constraints and reduced power system reliability and to provide solutions.

Brendan Kirby of ORNL was one of a panel of experts that helped DOE conduct the NTGS. Public input to the NTGS was obtained through meetings in Detroit, Atlanta, and Phoenix. A group of researchers and industry experts then were asked to write six supporting reports for the NTGS. (Kirby is lead author on one of the reports and a co-author on a second.) The cover report, which integrates the six issue papers and provides final recommendations, was published in May 2002 (see www.energy.gov).



Investment in the transmission grid has declined for over 20 years. The blue line shows actual investment; the gold line indicates the projected investment trend; the red line indicates projected investment through 2002.

Interest in a national transmission grid has arisen because competition in the wholesale electricity market has changed the way U.S. electric grids are used. Transmission systems designed to move power within small service areas are now frequently stressed to their limits by the regional movement of large blocks of power. These new patterns, growing demand for electricity, and reduced investment in transmission facilities have caused transmission congestion across the country. Removal of transmission bottlenecks will support a wholesale market that allows electricity to flow freely to multiple load centers, reducing costs and inviting investment in transmission systems.

The NTGS recommends regulatory and market-based approaches to stimulate investment in a national "transmission superhighway" and identifies research areas that would benefit from federal support.

ORNL is in the process of developing a National Transmission Test Facility to aid in evaluating advanced overhead conductors and developing advanced transmission line instrumentation. As planned, the facility will be built and operated in collaboration with the Tennessee Valley Authority.

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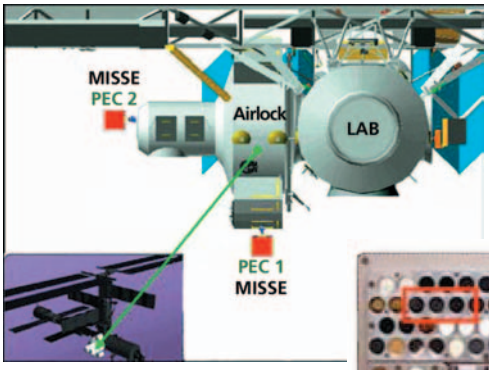
Sponsor: DOE/EERE Distributed Energy and Electricity Reliability

ORNL's Graphite Foam Boards the International Space Station

Samples of graphite foam developed by James Klett of ORNL recently traveled on the space shuttle *Discovery* to a destination aboard the International Space Station. The Materials International Space Station Experiment, or MISSE, consists of two suitcase-like containers, each holding hundreds of samples of advanced materials. Shuttle crew members attached the suitcases to the outside of the space station and opened them to the harsh environment of space. The materials will remain in space for 1 year. Then they will be returned to earth, where scientists will examine the materials and study the effects of the exposure.



Left: *Approximate location of the advanced materials samples on the International Space Station.* Below: *Red outline indicates graphite foam samples in the collection of materials.*

Graphite foam is a patented open-cell material with ultra-high thermal conductivity. Researchers foresee many potential uses of the foam in the thermal management of power electronics and other equipment in satellites, space stations, and shuttles.

Its high conductivity and very high surface area make graphite foam ideal for use in heat sinks for cooling high-power electronics. The foam exhibits thermal conductivity as high as that of aluminum but at only 20% of its weight. This characteristic has lead to development work in the area of cooling systems for power electronics that can dissipate significantly more heat than conventional heat sinks. In addition, prototype automobile radiators made of graphite foam have been demonstrated that are two-thirds the size of conventional cooling systems. One of these was tested in a vehicle in races leading up to the 2002 NASCAR Daytona 500. It is anticipated that numerous other types of systems that must dissipate heat will benefit from the unique properties of the graphite foam.

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Sponsor: DOE/EERE FreedomCAR and Vehicle Technologies Program

Efficient, Clean, Safe Trucks for the 21st Century

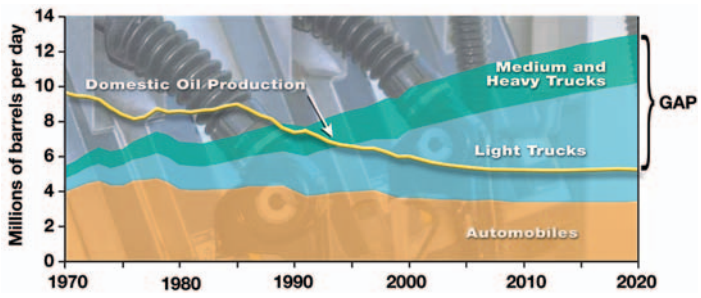
Safety, fuel economy, and emissions are the focus of ORNL's heavy vehicle R&D.

Dependence on imported oil in the United States has grown from 35% to almost 55% since 1973. To meet the growing oil demand, the United States imports 10 million barrels a day (24% of it from the Middle East) at a cost of $2 billion a week. This increasing dependence on imported oil is due primarily to growth in consumption by light and heavy trucks.

Trucking is essential to the nation's economy: trucks carry over 80% of the nation's freight. New technologies are needed to enhance our energy security by improving the fuel economy in trucks, and to reduce emissions from diesel engines to satisfy new requirements established by the Environmental Protection Agency (EPA). Partnerships between government and industry are vital to meeting these challenges. The 21st Century Truck Partnership (21CTP), initiated in April 2000, is an example of this public/private cooperation. DOE is the lead agency in the 21CTP, working with the Department of Transportation, the U.S. Army, and EPA in collaboration with 16 major trucking industry companies. The research programs include research on engine technology, vehicle systems, materials, hybrid propulsion, and alternative fuels.

ORNL researchers are key players in the 21CTP. Dave O'Kain recently completed an assignment at DOE-HQ to provide technical assistance in the 21CTP coordination office, and Johney Green has begun a similar assignment. Ron Bradley led preparation of the 21CTP *Technology Roadmap* document in 2001.

ORNL researches a wide variety of truck technologies. For example, the Fuels, Engines, and Emissions Research Center (FEERC) at the National Transportation Research Center (NTRC) conducts engine and emissions R&D on a variety of truck engines, mostly diesel-powered, using different fuel formulations, various emissions control strategies, and various aftertreatment devices such as NO_X adsorbers and urea-selective catalytic reduction catalysts. FEERC staff work closely with colleagues in companies that manufacture trucks, engines, and emissions control equipment on many aspects of diesel engine performance. (See www.ntrc.gov.)



Projected gap between U.S. oil demand and production. Trucks account for a growing portion of imported oil use.

NTRC is also establishing a Heavy Vehicle Safety Research Center where government and industry research can collaborate to address safety issues for heavy vehicles and the reduction of truck-related fatalities. Research in the first year of operation will concentrate on brake systems safety and infrastructure.

ORNL's High Temperature Materials Laboratory conducts R&D on materials for the entire range of truck systems. Projects include research on metals, ceramics, glass- and carbon-fiber composites, and carbon foams. Much of the R&D is dedicated to increasing fuel efficiency through the application of better materials that allow engines to operate at higher temperature. This requires improving the high-temperature strength of metals and alloys and the use of ceramics and insulations. Lower vehicle weight also improves overall efficiency, so ORNL is leading a major effort to develop and apply lighter-weight materials, such as aluminum, magnesium, and polymer matrix composites.

The 21CTP encourages close cooperation between industry and the national laboratories, and ORNL is involved in several new projects with industrial partners. In the fuels and emissions areas, partners include Cummins Engine Company, Catepillar, and Detroit Diesel Corporation. These companies are also partnering in R&D on engine materials. International Truck and Engine Company, Volvo, Freightliner, Mack Truck Company, PACCAR, and others are collaborating on vehicle-related technology development.

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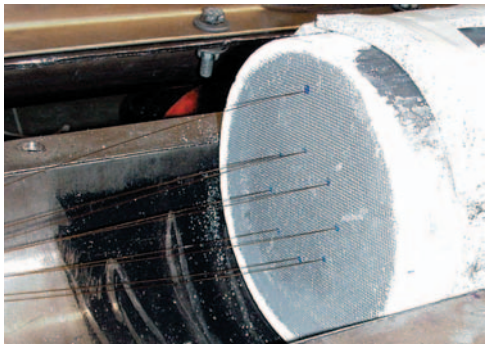
Sponsor: DOE/EERE FreedomCAR and Vehicle Technologies Program

SpaciMS Provides Quick, Accurate, Emissions Analysis



Capillaries inserted in a catalyst for SpaciMS measurement.

Diesel engine manufacturers are under pressure to develop more effective diesel exhaust treatment technologies to meet increasingly stringent regulations. ORNL researchers Bill Patridge and Sam Lewis have developed a measurement tool that provides critical insights for improving the performance of catalysts and exhaust gas recirculation (EGR), two areas where breakthroughs are essential.

Catalysts (e.g., materials that trap NO_X, sulfur, or particulates) are typically applied as coatings on honeycomb-type fil-

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New Spark Plug Ignites Potential of Natural Gas Engines

A new type of spark plug for transportation and stationary power invented at ORNL could help improve fuel economy and reduce emissions in reciprocating engines using natural gas or other hard-to-ignite fuels.

On an ordinary spark plug, an electrical arc crosses an air gap to hit the electrode and initiate a spark at nearly the same point every time. On the rotating arc spark plug (RASP), a magnetic field surrounds the electrode, causing the arc to hit different points on the electrode in successive spark events. Moreover, when the arc contacts the electrode, it travels around the entire surface instead of hitting just a single point. There are several advantages to this approach:

The rotating arc spark plug (shown alone and mounted in a cylinder head) improves combustion under ultra-lean conditions.

- Because the arc contacts more of the fuel volume, the RASP starts combustion more reliably than conventional plugs.
- The RASP produces a much higher plasma temperature, making it easier to initiate an arc.
- The wear on the electrode is reduced by more than one order of magnitude because its surface has more chance to cool between hits, and by another order of magnitude because of the large electrode area.

Because of its higher-power spark, lower erosion rate, and reduced misfiring, the RASP could eliminate the ignition disadvantage for natural gas. In addition, the RASP allows an engine to use a leaner fuel mixture (a higher ratio of air to fuel). A leaner mixture greatly increases fuel economy while reducing exhaust emissions.

Further development of the RASP will focus on improving its reliability and durability over extended periods of use in an engine.

A companion invention, a new erosion measurement technique, allows researchers to analyze the performance of the RASP and of conventional ignition sources. The basis of the technique is a unique, easily identifiable spectral signature of the vaporization produced by every spark event. That signature is used to measure the anode erosion due to the spark discharge and the cathode erosion that occurs in the arc phase.

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Sponsors: DOE/EERE FreedomCAR and Vehicle Technologies Program, Distributed Energy and Electricity Reliability

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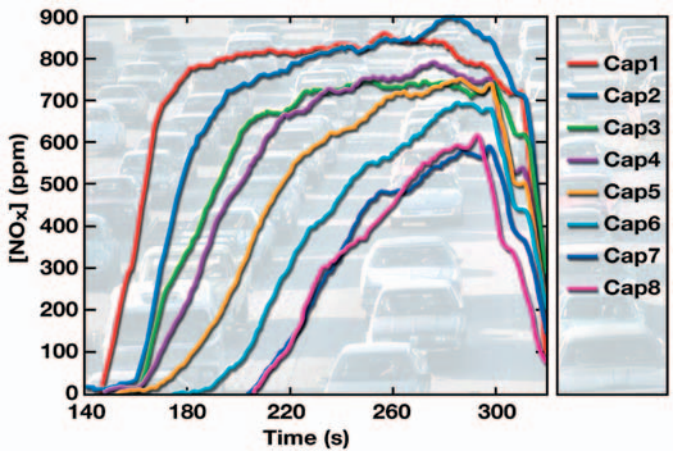
ters with channels that are millimeters wide and several inches long. As exhaust emissions travel along the channels, constant subtle changes occur in their chemistry. Measurement techniques that can resolve these spatial and temporal variations are required to clarify detailed catalyst parameters so catalyst models can be developed. Similarly, efficient EGR requires an EGR/air charge that is well mixed and uniform among cylinders for optimum NO_X control. Methods of evaluating the EGR/air charge must be minimally invasive, so the measurement tool itself does not create additional mixing in the charge.

The ORNL invention, the spatially resolved capillary-inlet mass spectrometer (SpaciMS) has the quick response and minimally invasive nature required for precise, high-speed emissions analysis. Moreover, it can measure a broad range of gases; conventional instruments are typically dedicated to a single species.

The instrument uses tiny (~160-μm outside diameter) glass capillaries inserted into the emissions stream to extract samples (~12 to 60 μL/min) and transport them to the mass spectrometer, which performs at kilohertz rates. The instrument is portable and has been deployed to industrial research labs to evaluate advanced emission-control systems.

In conjunction with industrial partners, ORNL has used the SpaciMS to evaluate advanced exhaust treatment systems for heavy-duty diesel applications.It has been applied by Cummins and EmeraChem to resolve NO_X distributions throughout operating NO_X adsorber catalysts and SO_2 and H_2S distributions in sulfur traps. Cummins has used the SpaciMS to evaluate the performance of EGR system designs for a medium-duty V8 diesel engine Cummins is developing.



Intra-catalyst-channel NO_X distributions charted across space and time at the capillary locations during the adsorption phase.

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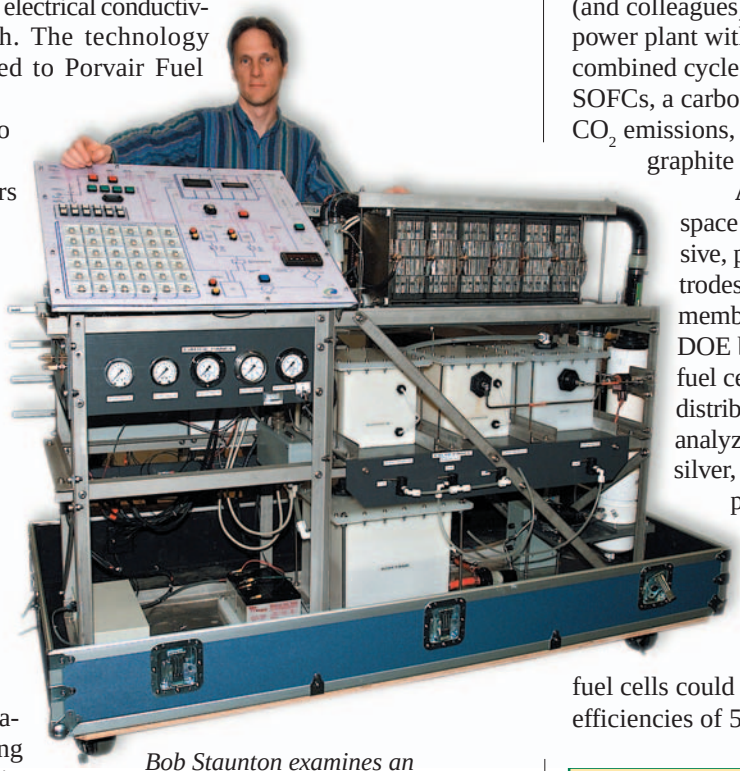
Sponsor: DOE/EERE FreedomCAR and Vehicle Technologies Program

Diverse ORNL Expertise Powers Fuel Cell Research

ORNL is a center of expertise in many research areas essential to advancing fuel cells as an energy source—materials, power electronics, computer modeling, catalysts, and electrochemistry. Our researchers are finding ways to reduce cost, size, and weight and improve the performance of fuel cells to power both vehicles and buildings. Work is under way on projects involving polymer electrolyte membrane (PEM), solid-oxide, and alkaline fuel cells (each named for the type of electrolyte membrane used).

PEM fuel cells use a membrane similar to ordinary plastic wrap. The PEM is favored to power vehicles because it warms up quickly and is sufficiently power-dense to be comparatively small—about suitcase size. A major drawback to using PEM fuel cells in cars is their heavy, expensive graphite plates. However, ORNL's Ted Besmann and his colleagues have developed a method of manufacturing carbon composite plates that are much lighter and cheaper and that meet R&D goals for cost, performance, corrosion resistance, electrical conductivity, and strength. The technology has been licensed to Porvair Fuel Cell Technology.

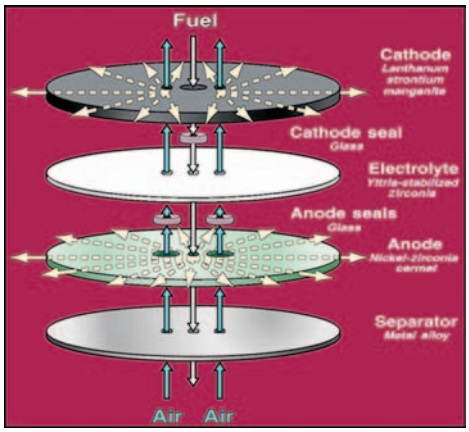
ORNL also is working with industrial partners (e.g., MER and W. L. Gore) toward thinner, lighter electrolytes and electrodes with good power density. They are experimenting with alternative materials (e.g., a titanium nitride film on an iron-titanium base) for structure–property relationships, analyzing engineering designs, developing prototype fuel cells, and evaluating their performance.



Bob Staunton examines an alkaline fuel cell at the National Transportation Research Center.

To advance R&D on fuel cells for residential use, ORNL's Buildings Technology Center is monitoring the performance of a home-size PEM unit (see article on next page).

ORNL supports the development of **solid-oxide fuel cells** (SOFCs) through materials development, design work, and modeling. These fuel cells, which operate at a high temperature (1000°C), are best suited for stationary applications providing electricity to factories and towns. SOFC plates and membranes made of novel nanocrystalline films synthesized at ORNL exhibit many-fold greater conductivities, and can operate at much lower temperatures, than those made from conventional materials. These developments could allow manufacturers eventually to reduce SOFC size by 75% and weight by 50% and reduce the price significantly from the present $1500/kW.



Schematic of a solid-oxide fuel cell.

SOFCs produce not only electricity but also steam that can drive a turbine, making them highly efficient. Using computer modeling, ORNL's Tim Armstrong (and colleagues) have designed a hybrid fuel cell–gas turbine power plant with an energy conversion efficiency of 80%. This combined cycle system incorporates a gas turbine, one or two SOFCs, a carbon-fiber composite molecular sieve to reduce CO_2 emissions, and a heat exchanger using high-heat-transfer graphite foam.

Alkaline fuel cells have been used in the U.S. space program since the 1960s. They are quite expensive, partly because they use platinum for their electrodes and catalyst, and their potassium hydroxide membranes degrade when exposed to CO_2. However, DOE believes different materials could make alkaline fuel cells sufficiently small and affordable for use in distributed power generation. ORNL researchers are analyzing the use of various materials (e.g., carbon, silver, metal oxides) to find the best candidates to replace platinum. To protect the alkaline electrolyte, ORNL has developed a carbon scrubber that removes CO_2 from air entering the fuel cell. The scrubber is regenerated by passing an electric current through it to release the adsorbed CO_2.

Researchers hope that eventually alkaline fuel cells could cost less than $100 per kilowatt and achieve efficiencies of 50–55%.

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OAK RIDGE NATIONAL LABORATORY
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Coming soon to your home?

Performance Monitoring of Family-Size Fuel Cell

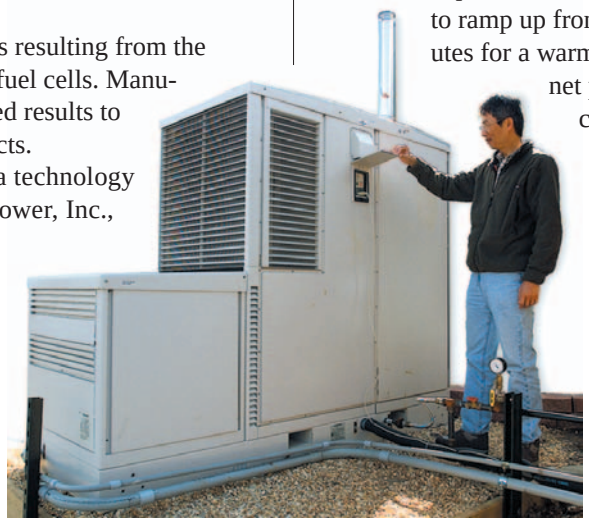
Although fuel cells for large buildings have been on the market for several years, units sized for residential use are still under development. Monitoring of a 5-kW fuel cell now under way by ORNL's Buildings Technology Center will provide data to help manufacturers refine the performance of home-size fuel cells.

DOE will use the data and insights resulting from the project to guide its R&D on residential fuel cells. Manufacturers will be able to use the published results to improve the performance of their products.

The fuel cell being monitored is a technology demonstration unit (TDU) from Plug Power, Inc., that is not yet on the market. For a fuel source, it uses natural gas, which is reformed to produce hydrogen. A chemical reaction inside a fuel cell acts upon the hydrogen and oxygen from air to produce a flow of free electrons (electricity) and water.

The Plug Power cell began operating in January. Characteristics such as power output; efficiency; ramp-up and ramp-down times; fuel, air, and water flow; and operating temperatures will be monitored. So far, the fuel cell has produced up to 5.2 kW net of electricity. It produces power continuously and has gone through several shutdown and start-up cycles.

Performance characteristics tested to date include cold and warm start-up and load variations. The fuel cell requires an hour to ramp up from cold start to full power, 15 to 20 minutes for a warm restart, and 2 to 5 minutes to change net power output from 2 to 5 kW. The fuel cell stack is running at around 70°C.



Fang Chen and others are conducting studies on the first residential polymer electrolyte membrane fuel cell unit operating in the Southeast.

BTC researchers hope to use waste heat produced by the fuel cell to regenerate an enthalpy wheel for air-conditioning, similar to the one being used in a geothermal heat pump project at a local school (see p. 3).

The manufacturer hopes to have its residential units ready for the consumer market in the near future.

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Sponsor: DOE/EERE Distributed Energy and Electricity Reliability Program

Designer Crops Shape Their Carbon Allocation

Meeting the projected demand for biomass-based products will not be a simple matter of planting garden-variety trees and grasses. It will require energy crops that store maximum amounts of carbon in desired configurations.

Plants "allocate" carbon between their above- and below-ground parts and "partition" it among three types of cell wall components — cellulose, hemicellulose, and lignin. The ideal biomass plant will have high-carbon stems, branches, and leaves that yield more fuel and/or chemicals when harvested and processed. It also will have a root system high in lignin, which will decay slowly and thus store carbon for longer times in the soil.

Plant scientists at ORNL are investigating the genomic-level processes that govern how plants allocate and partition carbon in hopes of developing the capability to customize biomass crops for specific purposes.

Two new techniques for characterizing wood chemistry (pyrolysis molecular beam mass spectrometry) and wood density (computer tomography X-ray densitometry) developed at National Renewable Energy Laboratory and ORNL, respectively, make it possible to examine large plant populations to determine the genetic basis for cell wall formation (partitioning). Using these techniques, researchers have identified two regions of the pine genome associated with cell wall composition. Based on this work, three hypotheses related to carbon allocation and partitioning have emerged: carbon allocation is controlled by a small number of genes; genes controlling partitioning operate independently above- and below-ground; and the genes that control allocation also affect partitioning.

To produce a hybrid poplar tree, flowers from the female are inoculated with pollen from the male. Hybrid progeny grow from the resulting seed.

The research team is studying wood tissue samples from 300 hybrid poplar trees, a promising biomass crop, to map the hybrid poplar genome. They hope within 2 years to identify the specific genes that control carbon allocation and partitioning in hybrid poplar.

Such a discovery would lead to a better understanding of the biological processes that underlie the production and use of biomass.

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Sponsor: DOE's Office of Basic Energy Research

Fighting fluff, fungus, and flames

Feedstock Engineering Considers Biomass as a Commodity

ORNL established the Feedstock Engineering Program in 2001 to complement ORNL's capability in bioenergy feedstock development. For the growing bioenergy industry to prosper, practical research is needed on feedstock modification and innovation in biomass-handling equipment to overcome inefficiencies associated with low density, flammability, degradation, and physical losses.

Feedstock engineering views biomass crops in their entirety, as a source of food, animal feed, industrial feedstocks, transportation fuels, and power. Its aim is to develop technologies to separate and use all the plant's components, increase the density of feedstocks for efficient handling and quality control, and integrate feedstock handling with conversion processes. Over the next several years, the industry is expected to grow to produce hundreds of millions of tons of biomass feedstocks.

Integrated crop handling systems that harvest the whole plant and separate it into its various usable parts—for example, grain, stalk, cobs, and leaves—would be attractive to producers. Such systems would need controls to return enough plant residue to the soil to maintain soil productivity. The fibrous part of the plant would be processed, stored, and transported to biorefineries as a bulk commodity meeting defined quality standards. Partial pre-treatment of the feedstock before bioconversion could take place on the farm or at the multi-farm level.

Baling equipment harvesting corn stover in the field demonstration.

Extensive in-house engineering and materials capabilities, combined with expertise in bioenergy research, make ORNL uniquely equipped for feedstock engineering R&D. The DOE program works closely with the farm and forest equipment industry, the U.S. Department of Agriculture, the National Renewable Energy Laboratory, and other research centers.

A recent project analyzed the harvesting and transport of corn stover (stalks and leaves) as a source of bioethanol feedstock. In consultation with experienced operators, ORNL researchers identified the most likely current sequence of operations for collecting stover and transporting it to intermediate storage. A baseline case was costed that consisted of shredding and raking, round baling, transporting to storage, and stacking bales under a shed using a telescopic handler.

The yield was 1.5 dry tons/acre. Costs up to and including intermediate storage were $27 per ton (exluding payment to the farmer for the stover and transport to a conversion facility). The researchers are now establishing the costs of alternative systems that add densification processes, change transport and storage options, reduce fire and dry matter losses, and reduce the amount of pre-conversion processing required at the conversion facility.

Another project conducted a detailed review and analysis of existing equipment potentially useful in biomass handling. Five areas of highly integrated R&D needed to achieve short-term objectives were identified:

- Moisture control and management
- Crop characterization from field to storage
- Machinery management and modeling
- Densification of loose biomass
- System engineering analysis and optimization

The multi-disciplinary nature of the Feedstock Engineering Program requires expertise from a wide range of research areas. Contacts have been made to identify interested scientists and engineers to participate in developing a strategic research plan.

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Sponsor: DOE/EERE Biomass Program

Whole-Crop Harvest Observed in Iowa

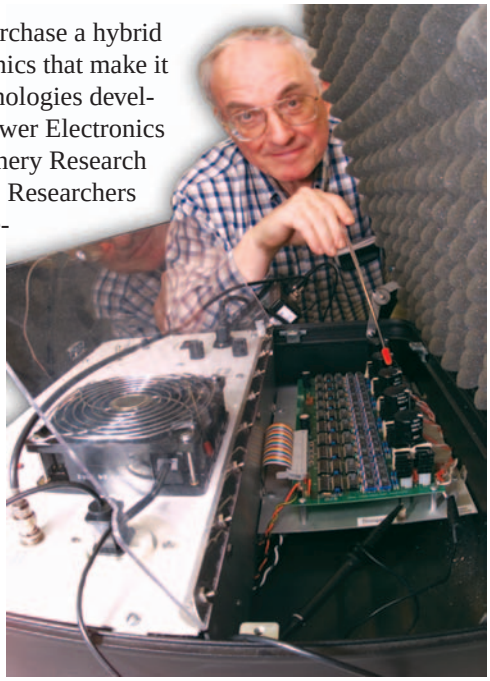
ORNL researchers Shahab Sokhansanj and Anthony Turhollow observed whole-crop corn harvesting in action on a recent visit to Iowa's farm country. The field demonstration occurred during a visit to Iowa State University and B/MAP Agriproducts to discuss feedstock engineering research and observe new approaches to harvesting corn stover.

The demonstration highlighted several preliminary equipment modifications that could be used to harvest corn stover simultaneously with grain. Auxiliary equipment was attached either to the front or the rear of conventional grain combines to chop and collect stover in a one-step operation. A working model of a large square baler was also demonstrated in the field.

The researchers toured a B/MAP Agriproducts operation that processes corn stover into fiber. The fiber is used as a reinforcement in plastic composites, in pressboard for building materials, for soil stabilization, and for gardening mulch. The project is dedicated to exploring uses of corn stover in a full-scale commercial setting.

Creating the Next Generation of Power Electronics

When you purchase a hybrid vehicle, the electronics that make it work may use technologies developed at ORNL's Power Electronics and Electric Machinery Research Center (PEEMRC). Researchers in the Center are developing advanced electronics for use in electric powertrains, energy storage devices, and many other applications in both hybrid and conventional vehicles.



John McKeever of the PEEMRC with a multilevel inverter that can serve as an interface between renewable resources and a higher-voltage power grid.

PEEMRC is DOE's research center for R&D in power electronics inverters and electric machines. The center has dramatically advanced the technology of soft-switching technologies, multilevel inverters, and efficient, compact electric machinery.

Working with industrial partners, PEEMRC is developing and evaluating automotive electric motor drives and addressing the integration of power electronics systems in vehicles.

Among the automotive technologies invented by ORNL researchers is a multilevel dc-to-dc converter to connect 12-V and 42-V electrical nets in automobiles. The design offers reduced size, weight, manufacturing cost, and electromagnetic interference compared with other converter technologies and is more than 99% efficient. Another invention, the high-strength undiffused brushless motor, increases power density and reduces drive system costs in hybrid vehicles by incorporating field weakening into the motor.

Simulation software written at PEEMRC is aiding the evaluation of motors and drives for hybrid vehicles. The interactive models allow users to see the impact of design changes on the weight, cost, and efficiency of a motor operated at various speeds and loads. Two permanent magnet simulators have been developed, and a switched reluctance motor model is under development.

The Center also addresses technology needs and issues in areas other than transportation, such as electric power transmission and distribution; distributed energy generation; and motors, drives, and inverters for industrial applications.

Located in the National Transportation Research Center near Knoxville, Tennessee, the PEEMRC includes more than 9000 ft^2 of modern lab space. Equipment includes a dedicated 600-V, 600-A bi-directional dc power supply; a high-speed rotational equipment safety tank; and a 100-hp, 1000-rpm, 4-quadrant dynamometer. For more information, see www.ornl.gov/etd/peemrc.

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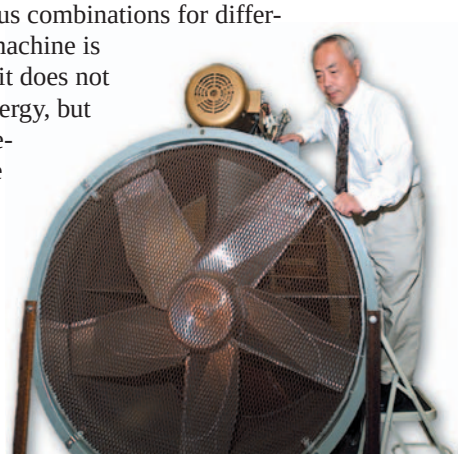
Affordable Adjustable-Speed Drives for Industrial Machines

Adjustable-speed drives (ASDs) could be a significant energy saver for users of industrial machinery. Unfortunately, the high first cost of conventional ASDs has hindered their widespread use. However, ORNL has developed a novel motor that offers adjustable-speed operation at a much lower cost than conventional ASDs.

Fans and pumps account for two-thirds of the motor drives used in industry, and most of them are driven by constant-speed motors. Unable to control their speed, users compensate by blocking part of the output with dampers when a lower flow is needed. The machine works as hard and uses as much energy for low output as for high. ASDs would save the energy being used to do unneeded work and enable equipment to operate more efficiently. DOE's Industrial Technologies Program estimates that better matching of motor and mechanical systems could save 41% of the energy used by industrial motors, more than any other improvement.

The hybrid secondary uncluttered induction machine (HSU-I) developed in the PEEMRC adds a section to a motor to make it adjustable with simple resistors and other low-cost components, rather than the adjustable-frequency inverters typically used in ASDs. "Hybrid secondary" refers to three types of secondary circuits— variable-resistance, inverter, and magnetic switch— used in various combinations for different applications. The machine is "uncluttered" because it does not transfer the rotation energy, but only the slip energy, between the rotor and the stator control coils.



John Hsu, developer of the HSU-I motor, examines a blower powered by the motor. The HSU-I enables adjustable-speed operation at a comparatively low cost.

An HSU-I system is expected to cost less than half as much as a conventional ASD. A conventional 10-hp ASD with inverter costs well over $5000, compared with about $575 to $750 for a 10-hp constant-speed motor.

The HSU-I is still in the development stage. Prototypes have been built and tested, and ORNL is seeking an industrial partner to cooperate in refining and commercializing the technology.

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News Briefs

Open House and Transportation Showcase

ORNL's National Transportation Research Center and High Temperature Materials Laboratory co-hosted the NTRC Open House and Transportation Manufacturers Showcase May 6–7. An estimated 250 representatives from more than 70 companies attended the Showcase.

Ray Boeman of ORNL (right) explains the function of a composites testing rig to (from left) Dick Ziegler of ORNL, Tom Gross of DOE/EERE, and Bob Purrell of MTS.

continued from p.2

humidity from 45 to 70%. The similarity of the conditions indicates use of the controllers did not compromise occupant comfort.

The next phase of the research will examine the ability of a next-generation Digi-Log controller to respond to real-time electricity prices. This capability would enable the hospitality industry to lower electricity costs while helping utilities avoid system-wide power disruptions.

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Sponsor: DOE/EERE Building Technologies Program

Heavy Vehicle Safety Research Center

A Heavy Vehicle Safety Research Center has been established at ORNL's National Transportation Research Center. The initial funding for the Center is a $1 million U.S. Department of Transportation grant. "Approval of this funding signifies the importance to the Congress of investing in the safety and security of our nation's highway system and motorists who use it," said Rep. Jimmy Duncan (R-Tenn.), who announced the grant.

Fuel Cell R&D Award

Ted Besmann, John Henry, Jr., James Klett, and Tim Burchell of ORNL were presented the year 2002 National Laboratory Fuel Cell R&D Award at the Fuel Cell Review Meeting in May in Colorado. The award was given by the DOE/EERE Fuel Cells Program in recognition of the team's development and eventual licensing of a carbon composite bipolar plate that has excellent properties and meets DOE cost goals.

Entrepreneurs for Energy Efficiency

Entrepreneurs for Energy Efficiency, a group of successful businesses whose ideas received funding from DOE/EERE's Inventions and Innovations Program, held an awards ceremony at the U.S. Capitol recently to recognize achievements in energy savings. Among the presentations was an award to DOE in recognition of the success of the I&I Program. ORNL organized the alumni group and facilitates its development.

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