Science & Technology HIGHLIGHTS

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Technology Transfer Repays Public Investment in R&D

For the past year or so, we've been telling you about the exciting R&D work going on in the Energy Efficiency and Renewable Energy Program at ORNL. One thing that we have not mentioned explicitly is how knowledge and results from our R&D are transferred in a useful way to industry users and to consumers. This "technology transfer" is of vital interest to us because it is how the taxpayers' investment is repaid; the ORNL EE/RE Program receives public funding, and in return the public receives products and processes that improve many aspects of life from economic well-being to environmental quality. So what's the best way to make all our wonderful R&D results available to consumers in products that will enrich our lives? There is no *one* best method; rather, we select a suitable mechanism from a broad array of possibilities.

National user facilities. Expert knowledge combined with unique, cutting-edge equipment and facilities can be accessed by private companies, other government agencies, and universities through national user facilities. This extraordinary access is available free of charge if the user agrees that the results of the work will be openly available in the public domain. (Companies who wish to remain anonymous or who wish to hold the results proprietary may do so, but they must pay for the facilities and staff time that they use.) ORNL has 15 national user facilities; 4 of them are sponsored by EE/RE: the High Temperature Materials Laboratory (Aug. 1998, p. 8); the Buildings Technology Center (Nov. 1998, p. 3); the Bioprocessing Research Facility (No. 1 1999, p. 5); and the Metals Processing Laboratory (this issue, p. 6). A company may conduct several research projects under one "user agreement," lessening the administrivia associated with use of these government facilities. There are currently more than 300 nonproprietary user agreements in place for these four facilities. Since October 1998, more than 150 projects have been conducted under these agreements.

ORNL materials researchers Ogbemi Omatete and Claudia Walls examine gelcast components.

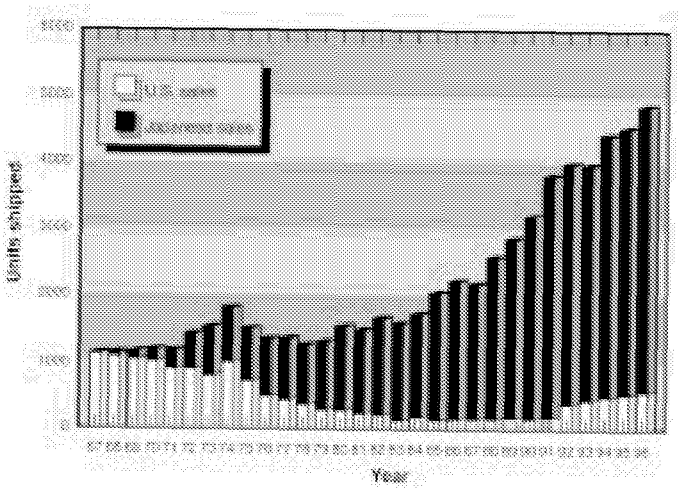
Technology patents and licensing. Researchers have patented numerous technologies as the result of work done by ORNL staff members or by industrial and university partners in DOE/ORNL programs. Many of the patents held by other organizations as the result of cost-shared research have led to successful commercial products such as high-efficiency compressors for refrigerators; ceramic water pump seals; vacuum insulation panels; and low-corrosivity, low-toxicity working fluids for chemical heat pumps. In addition, selected technologies are made available by DOE for licensing by industry. To date, these licenses have generated more than $3.8 million in royalties on sales of more than $170 million.

Cooperative R&D. Cooperative research and development agreements (CRADAs) offer industry a mechanism to partner with us without having to execute a formal contract with the government. Under a CRADA, DOE/ORNL and industry work together to solve problems of

(See Technology Transfer—page 5)

A Big Chill for a Little Power

Researchers in ORNL's Buildings Technology Center (BTC) have developed advanced chiller cycles that may represent the most significant improvements in chillers in two decades. If the triple-effect chiller units currently being tested perform as expected, they promise to result in substantial energy savings, reduced emissions, and increased competitiveness for U.S. manufacturers in global markets for large commercial chillers.



Comparison of U.S. and Japanese chiller sales.

Developed in partnership with two U.S. manufacturers, these natural gas–powered chillers deliver up to 40% more cooling efficiency in laboratory tests than double-effect units now on the market. A 450-ton prototype has been undergoing laboratory testing at York International's Developmental Test Facility in York, Pennsylvania, since 1998. York International and ORNL are preparing to field-test a next-generation triple-effect chiller in a public building in Clark County, Nevada (see highlight article), later this year. Trane is conducting laboratory tests of a prototype triple-effect unit that uses a technology licensed from ORNL.

The chiller York will test in Nevada uses an absorption cycle patented by ORNL. The "triple effect" refers to feeding an absorbent solution (lithium bromide and water) through low-, medium-, and high-temperature generators. The high-temperature condenser that receives refrigerant vapor from the high-temperature generator is also coupled to the other two generators. This arrangement increases internal heat recovery within the system, increasing its efficiency and reducing emissions. The chiller's emissions of carbon dioxide, sulfur dioxide, and particulates are 99.9%, 73%, and 99% lower, respectively, than those of double-effect chillers.

U.S. manufacturers had 100% of the market for single-effect absorption chillers 30 years ago. However, Japanese manufacturers now dominate the market worldwide. U.S. sales have increased in recent years, mainly because U.S. manufacturers have licensed Japanese technologies, but Japanese companies account for most sales. The triple-effect chiller is expected to help U.S. chiller makers recapture a share of the global market.

These advanced gas-fired chillers use no chlorofluorocarbon or hydrochlorofluorocarbon refrigerants. Because they consume less energy, they will help users lower energy bills, help utilities reduce peak loads, and indirectly help reduce emissions from power plants that contribute to global climate change.

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Sponsor: Office of Building Equipment

Chiller of the Future Opens in Vegas

The hot, dry climate of southern Nevada will be the testing ground for a new triple-effect absorption chiller developed by ORNL and York International. Developers of the advanced natural gas–powered chiller hope it will prove to be significantly more efficient than the chillers that are currently available.

The demonstration unit will be field-tested in the newly constructed Clark County Government Center in Las Vegas beginning late this year or early in 2000. Field testing will continue for 12 to 18 months. ORNL will provide technical assistance and monitor the test site, chiller unit, and operation.

The unit will provide 400 tons of cooling capacity to cool the six-story, 385,000-ft^2 building. Previous tests have indicated that the new technology will improve cooling efficiency by up to 40% compared with the double-effect chillers that currently dominate the market. In addition, the triple-effect chiller uses environmentally benign refrigerants that do not harm the ozone layer or contribute to global warming.

In announcing the field test, Energy Secretary Bill Richardson said the new technology "may be the way we cool buildings that use chiller systems in the future." If the system proves effective and as efficient as expected, "then its implications for the environment are critical." Richardson also noted that such units may be powered by hydrogen in the future, which would make them even more environmentally friendly.

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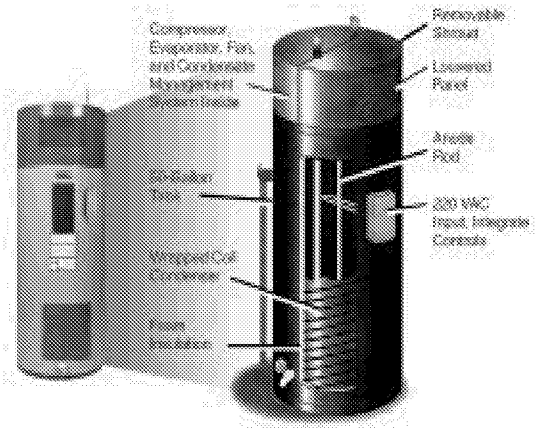
"Drop-in" HPWH Can Slash Costs for Water Heating

Water heating accounts for about 17% of the energy consumed in a typical household, making it a good candidate for energy savings. However, conventional electric water heaters are reaching their efficiency limits. New technologies, not just improvements to existing ones, are needed.

ORNL's Buildings Technology Center is providing technical support for development and field testing of a "drop-in" heat pump water heater (HPWH) from a U.S. manufacturer that represents a leap in water heating technology. ORNL will assist in development; develop testing criteria and protocols; coordinate the testing; collect, analyze, and distribute the data; and aid in promoting the technology through DOE's Energy Star Program.

An electric HPWH is much more efficient than conventional units, reducing the electricity needed for water heating by about half. However, HPWH sales have been small because consumers are unfamiliar with the technology, first costs are high, and early models that were unreliable and difficult to install discouraged consumer interest. The new HPWH was designed with those issues in mind.

Earlier HPWH models were not well suited to replace existing water heaters. The new model, however, is designed as a "drop-in" replacement for a conventional 50- or 80-gallon electric water heater, having the same footprint, electrical hookup, and plumbing requirements. It can be installed anywhere a conventional electric model can be, and it can be installed by a plumber without any specific training for HPWH installation.



The installed cost of the new HPWH will be about $375 to $400 more than for a conventional 50-gallon water heater, but the energy savings can yield a 1-year simple payback. The HPWH's efficiency rating is expected to be around 2.0, compared with 0.95 for the most efficient conventional electric unit. An HPWH can be installed where there is no floor drain, but where one is available, the unit will provide space cooling and dehumidification as well as hot water.

The initial field test will be followed by a larger field demonstration and promotion effort that will include open utility participation and selected monitoring in partnership with the utilities. A commercial launch for the HPWH is anticipated in 2000.

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ORNL Helps Agitate for Advanced Washing Machines

High-efficiency machines cut water and power consumption

Bern, Kansas, a small town in the dry Western prairie country, was the site of a successful DOE-sponsored demonstration of a high-efficiency washing machine that requires dramatically less water and power to wash a load of clothes.

In the 1997–98 Bern study, average water usage for a load of washing fell 38%, from 41.5 gallons to 25.8 gallons, in households that switched from conventional washers to high-efficiency horizontal-axis washers supplied by Maytag. Energy consumption (mainly for water heating) declined 58% with the high-efficiency machines. In addition, the new machines left 7% less moisture in clothes after the spin cycle, reducing the amount of energy required to dry clothes.

Staff from ORNL helped set up the testing system and collect and analyze the data from the Bern demonstration. ORNL is now aiding DOE in an effort to promote sales of high-efficiency washers in the United States. Utilities, water as well as electric and gas, also are involved in the push.

It appears to be working. The Consortium for Energy Efficiency, a utility-supported group, notes that manufacturers have doubled (from 15 to 30) the number of high-efficiency washers offered in U.S. markets in the past 12 months. Seventeen states have established programs to promote high-efficiency washers, most of which offer incentives such as rebates or tax credits as well as consumer education.

According to ORNL's John Tomlinson, all major U.S. manufacturers now offer washers with efficiencies more than double the minimum set by the National Appliance Energy Conservation Act. "This should give consumers a great choice of efficient washers, spur competition, and lower prices among these machines," he noted.

The market penetration of high-efficiency washers in the United States is currently estimated at only 5 to 6%. Officials at DOE and other conservation agencies hope that the Bern experience will spur interest in high-efficiency washers among U.S. consumers.

For more detailed information, see the full report at www.energystar.gov/products/clotheswashers/bern.html.

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ORNL Continues Tradition of Cooperation with Aluminum Industry

ORNL was one of the first national laboratories to develop cooperative R&D arrangements with the U.S. aluminum industry, and that tradition of cooperation continues with several laboratory projects addressing areas of importance to the industry.

The aluminum industry is one of the American industry groups participating in DOE's Industries of the Future program. Through IOF, ORNL has aided aluminum industry representatives in preparing a technology road map to guide R&D planning, and ORNL's H. W. Hayden is the vice-chairman of a group of experts assembled to assess prior research and prioritize potential R&D in areas related to aluminum industry issues.

In cooperation with the Aluminum Association, ORNL is exploring the problem of molten metal/steam explosions in aluminum casting (see accompanying article). The laboratory also is part of a consortium to develop aluminum sheet material that does not require heat treatment for automotive applications. The partnership, which involves producers, professional associations, and national laboratories, is pursuing research to develop lower-cost aluminum alloys with properties similar to those of heat-treated alloys. The effort led to the development of new alloys that have been produced in commercial-size lots and are undergoing testing by automotive stampers.

ORNL has participated in a similar program for developing advanced sensor systems for use in aluminum reduction cells. Laboratory researchers are also building interactions with several university centers of excellence in technologies related to aluminum industry research needs, such as the newly formed Southeast Center for Aluminum Technology at the University of Kentucky and the Materials Processing Institute at Worcester Polytechnic Institute.

Several ORNL user facilities have conducted research for aluminum industry partners. Aluminum roofing materials are being evaluated at the Buildings Technology Center. Process simulation studies have been conducted through the Computational Center for Industrial Innovation. The High-Temperature Materials Laboratory has completed residual stress determinations of welded aluminum structures, and 18 individual programs have been carried out through the Metals Processing Laboratory.

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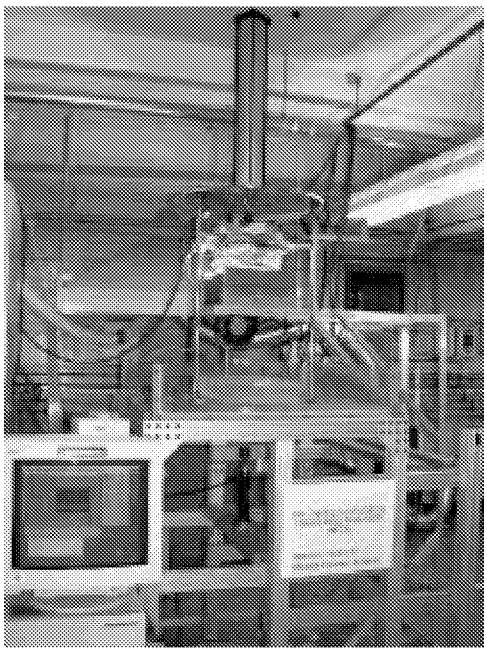
META Helps Stop Melt-Water Explosions Before They Start

Melt-water explosions can occur when materials such as aluminum, steel, magnesium, or nuclear fuel melt in the presence of water. In aluminum casting operations, melt-water explosions can cause injuries and damage to facilities.

Industry research has determined that certain organic coatings on submerged surfaces can prevent explosions, but the underlying physics of explosion onset are not known. ORNL has entered into a CRADA with the Aluminum Association to expand the knowledge base and help develop methods of preventing explosions.

The melt-water explosion triggering analyzer (META) developed at ORNL is helping determine causes and prevention mechanisms for explosion onset. Existing techniques (dropping up to 50 lb of molten aluminum into water) indicate onset but do not provide insights on the triggering phase. META provides such crucial data over a wider range of conditions and does so 5 to 20 times faster and at 5 to 10 times less cost per test. META permits the impact of effective masses ranging from a few to more than 1000 lb.

Data from META have led to a key discovery: organic coatings that prevent explosion onset do so because non-condensible gases (NCGs) are released under thermal attack. Field trials are scheduled to test whether introducing NCGs such as air at vulnerable locations might prevent the onset of explosive boiling. If the tests are successful, the method promises to offer a cost-effective, environmentally friendly alternative to current practice, which involves coating and maintenance of casting pit walls and steel work and results in extensive downtime.



The melt-water explosion triggering analyzer developed at ORNL.

The aluminum industry has selected META as the centerpiece technology to assess the ability of organic coatings in various curing stages to suppress explosion initiation. It is also being used to design a test apparatus to further validate the NCG injection scheme. Data from META tests are to be used to conduct field tests at Alcoa Technical Center using 50-lb molten metal drops.

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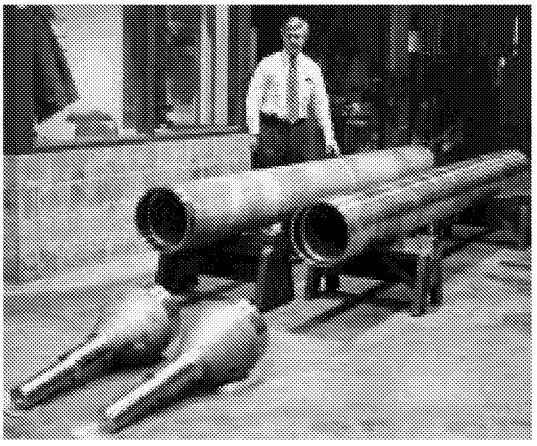
Sponsor: Office of Industrial Technologies

ORNL's AIM Research Develops Stronger, Tougher, Lighter Materials

The Advanced Industrial Materials (AIM) program works to develop new and improved materials for U.S. industries. AIM supports the "Industries of the Future" effort with the aluminum, chemicals, forest products, glass, metalcasting, refinery, and steel industries and recently expanded its efforts to the cross-cutting industries of carbon products, forging, heat treating, and welding. The IOF industries have identified the high-temperature strength, corrosion resistance, and wear resistance properties of materials as being particularly important.

ORNL supports AIM with numerous R&D projects. Some of these are described below.

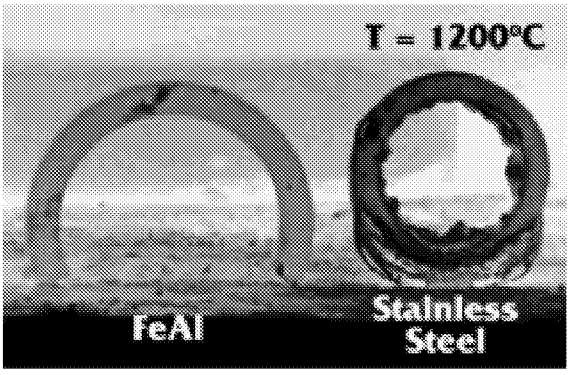
Nickel aluminide alloys in industrial applications. Alloys based on Ni_3Al are well suited for high-temperature applications because of their resistance to oxidation and carburization and their yield strength at temperatures of up to 1100°C. Exo-Melt, an energy-efficient process that ORNL developed for melting nickel aluminides, paved the way for their commercialization. ORNL is now involved in evaluating nickel aluminide products in industrial settings. Ni_3Al trays for carrying parts through heat-treatment furnaces and transfer rolls of Ni_3Al alloy in a steel mill furnace have been in service for several years without signs of deterioration, and forging dies made of Ni_3Al have had a production life 10 times longer than dies made of conventional material.



Prototype nickel aluminide transfer rolls for steel mill before installation.

Kraft boiler materials. ORNL is working with paper industry partners to identify the cause of and solutions for cracking of wall and floor tubes in black liquor recovery boilers at paper mills.

FeAl alloys. Intermetallic alloys based on FeAl could replace some stainless steels and other iron alloys because FeAl is so highly resistant to oxidation and corrosion at high temperatures. The new alloys also are highly ductile and lighter and stronger than currently available stainless steels.



FeAl resists oxidation at high temperatures.

Casting modeling. ORNL is helping implement massively parallel processing of computer codes needed for R&D in high-integrity casting. Running the codes on massively parallel systems reduces computing times from weeks to hours. ORNL is implementing the ProCAST software from UES on its parallel Intel Paragon processor, and centrifugal casting of Ni_3Al transfer rolls is being modeled to improve the casting process.

ORNL also conducts research in the uniform droplet process and in improving glass refractories and helps oversee several AIM projects under way at other laboratories.

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Sponsor: Office of Industrial Crosscut Technologies

("Technology Transfer" continued from page 1)

mutual interest, with both parties sharing the cost. To date, ORNL's EE/RE Program has participated in 87 CRADAs, representing almost $36 million in DOE funding and an astounding $45 million in cost-sharing contributed by industry.

Industrial assignments. Some of our researchers and engineers spend extended periods "on assignment" at industrial laboratories. They work hand-in-hand with industry to prove technologies using commercial techniques in real-world settings. This experience is invaluable from our point of view, giving our researchers exposure to industrial perspectives on manufacturability and cost. From our industry partners' point of view, the day-to-day interaction accelerates the introduction of new technology in products and processes.

We hope that in reading through the *S&T Highlights* you will see something that might be what your company needs to make a product stronger, greener, or cheaper. When you do, please give us a call to discuss how we might work together.

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MPLUS Facility Helps Users Solve Tough Metal-Processing Problems

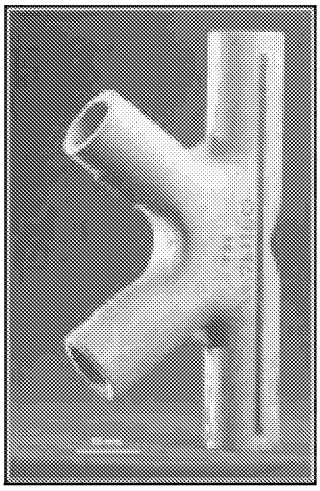
ORNL's Metals Processing Laboratory Users Facility (MPLUS) is designed to solve problems that limit the development and implementation of emerging metal-processing technologies. MPLUS offers specialized equipment and expert knowledge that can help in developing novel metallic materials and processing techniques, and tailoring them for specific applications in collaboration with industry and academia.

MPLUS was designated as a DOE National User Facility in 1997. Since that time, MPLUS facilities and staff have assisted more than 60 companies and universities in more than 85 R&D projects. MPLUS includes four primary centers devoted to improving U.S. industrial products and processes. These four centers specialize in processing, joining, characterization, and process modeling.

The ***metals processing*** lab is currently working on castable and weldable intermetallics. These advanced alloys are suited for industrial applications requiring high temperatures and corrosive environments. Other capabilities in the metals processing lab include expertise in casting, powder metallurgy, deformation processing (forging, rolling, extrusion), melting, and thermomechanical processing.

The ***metals joining*** lab offers a wide range of conventional and advanced joining processes; weldability testing, including the Gleeble system for process simulation; brazing facilities, including those for characterizing wettability; and vision systems for viewing weld pool dynamics. Other areas of investigation include welding processes, monitoring and control, solidification, brazing, bonding, and weld modeling.

The ***metals characterization*** lab offers facilities to characterize materials according to American Society for Testing and Materials and American Society of Mechanical Engineers codes. This facility also develops innovative test methods when they are needed and works with the appropriate standards organizations to institutionalize the tests. Areas of interest for metals characterization include corrosion, fracture mechanics, mechanical properties, microstructure, nondestructive evaluation, and properties databases.



A cast component used in the pulp and paper industry. ORNL and ABB C-E Services are collaborating through MPLUS to optimize the casting process design and eliminate defects. The project is likely to lead to a 50% improvement in the yield and cost of the casting, as well as improved performance of the unit where it is used.

The ***process modeling*** laboratory provides access to high-performance, massively parallel computing resources coupled with computer models to predict thermal gradients, molten metal flow, phase equilibria, solidification rates, strain distributions, residual stresses, and other characteristics. Capabilities include mathematical design and analysis, high-performance computing, process modeling, solidification/deformation, microstructural evolution, computer-controlled dilatometry, phase transformation, continuous cooling transformation and time-temperature transformation diagrams, and thermal expansion coefficients.

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Sponsor: Office of Industrial Crosscut Technologies

MPLUS Helps U.S. Chainmaker Stay Ahead of Foreign Competitors

Technical assistance from MPLUS has helped Morristown, Tennessee–based Jeffrey Chain remain ahead of its foreign competition.

Jeffrey is the only remaining domestically owned full-line chain manufacturer in the United States. The company needed to improve the wear, corrosion, fatigue, and impact properties of its materials without greatly increasing their cost, so it sought assistance from MPLUS in investigating the effects of cryogenic treatment of steel parts.

Staff members at MPLUS carried out cryogenic testing of different steel components using liquid nitrogen. Research staff at Jeffrey then measured the changes in properties in the treated parts. The results indicated samples with higher carbon content showed the most improvement in wear resistance as a result of the cryogenic tempering. Jeffrey then focused on using heat treatment to increase the carbon content of the company's components.

David King, the chief of metallurgy at Jeffrey commented that partnering with MPLUS is "one of the few ways we can conduct research and development in a timely manner. We are so busy trying to stay ahead or equal to the increased foreign competition that we have little or no time for what keeps us ahead—new products that are proven and superior." Access to user facilities such as MPLUS is a productive way for U.S. companies to receive technical assistance and take advantage of the resources of ORNL to help them compete successfully in global markets, he said.

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Sponsor: Office of Industrial Crosscut Technologies

ORNL Pursues Lower-Cost Carbon Fibers for Lighter Vehicles

Carbon fiber composites are the lightest material available for making primary automotive structures. Their use in automotive structures could reduce the body and chassis weight of vehicles by more than 60%. The use of these advanced lightweight composites in the auto industry is limited because carbon fibers are more expensive than traditional materials.

The biggest cost factors in producing carbon fibers are precursor materials (45 to 60% of production costs) and capital equipment (25 to 40% of costs). Large-scale use of carbon fibers by the auto industry would require prices of no more than $3 to $5 per pound; those prices are not possible with currently available precursors and processing technologies.

DOE's Office of Advanced Automotive Technologies, in conjunction with domestic auto makers, carbon fiber suppliers, universities, and the national laboratories, has developed a coordinated research portfolio to explore ways to bring down the costs of carbon fiber for high-volume uses. The effort addresses precursor cost, fiber preconditioning, and high-temperature processing. ORNL is researching the use of alternative energy sources in manufacturing high-quality, low-cost carbon fibers (see highlight article). ORNL is also initiating research to identify low-cost precursor materials that are alternatives to conventional materials. Candidates include recycled and organic-based materials, low-cost polymers, and coal-derived products.

Successful use of these materials would reduce the cost of precursor materials to $0.20 to $1.20 per pound (compared with the current $3.20 per pound), bringing the cost of the resulting carbon fibers within the range necessary for widespread use by domestic automakers and other high-volume manufacturers.

Early use of the next generation of advanced materials by the domestic auto industry will help establish U.S. industry leadership and secure the future of many American workers.

By: Dave Warren, 423-574-9693, warrencd@ornl.gov
Sponsor: OAAT Lightweight Vehicle Materials Program

Carbon Fiber Production—Faster, Cheaper, Better with Microwaves

Research conducted at ORNL has demonstrated the technical viability of microwave heating of polyacrylonitrile precursors to produce carbon fibers as an alternative to conventional thermal processing.

Results indicate microwave processing produces fibers that are comparable in density, electrical resistivity, and diameter to fibers produced conventionally. Microwave processing times are 5 to 8 minutes, compared with conventional processing times of 40 to 90 minutes. Fiber strengths after microwave processing exceed 340,000 psi, and the modulus (a measure of stiffness when pulled) exceeds 27 million psi (about the same as steel) without pretensioning of fibers. Researchers project that adding tensioning to the process will yield even stronger and stiffer materials than those obtained with conventional processing.

Microwave processing units are smaller, cheaper, and more energy-efficient than the huge ovens used in conventional thermal processing of carbon fibers. If microwave processing is widely adopted, inexpensive equipment could replace 70 to 90% of the conventional fiber-processing line, which costs more than $10 million and accounts for 25 to 40% of processing costs. Cost models indicate that use of this technology could yield a 20% reduction in carbon fiber price and a comparable reduction in energy consumption.

The availability of low-cost carbon fibers will allow the development of ultralight, affordable vehicle structures that will contribute to reducing fuel usage and exhaust emissions without compromising vehicle safety.

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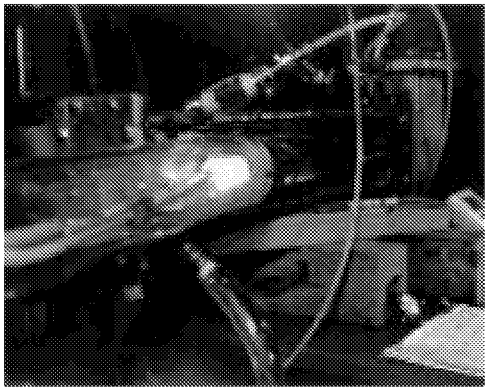
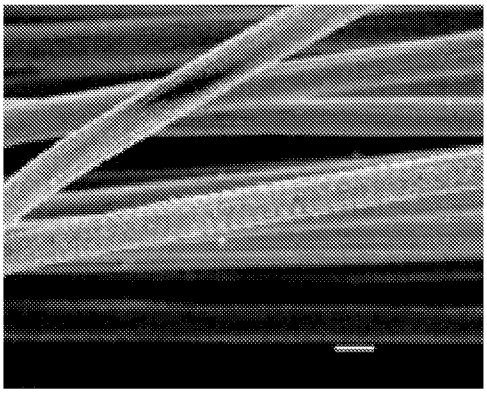
Sponsor: OAAT Lightweight Vehicle Materials Program



Processing of carbon fibers using microwave plasma (1500°C or greater).



This micrograph shows the very high quality carbon fibers produced by microwave processing.

CIDI Engines Are Efficient; ORNL Works to Make Them Cleaner

The compression-ignition direct-injection (CIDI) engine has been selected by the Partnership for a New Generation of Vehicles as the power plant most likely to meet efficiency and emissions goals for 2004. Although highly efficient, CIDI engines produce higher levels of some polluting emissions than do conventional engines, and ORNL is working to clean up their act before they go on the road.

The challenge to using CIDI engines in passenger cars is that they emit higher levels of oxides of nitrogen (NO_x) and particulate matter (PM) than gasoline engines. Meeting emissions standards in those areas without greatly reducing engine efficiency will require technology breakthroughs. ORNL is collaborating with industry on many of these, including innovations to alter the combustion process within the cylinder and methods to reduce emissions in the exhaust pipe.

CIDI engines emit higher levels of NO_x and particulates than gasoline engines. ORNL is working toward technology breakthroughs to reduce those emissions without sacrificing fuel efficiency.

In the area of in-cylinder combustion, ORNL is conducting two projects designed to extend the practical limits of exhaust gas recirculation, a method commonly used to reduce NO_x emissions. Several projects are under way in innovative concepts for controlling exhaust emissions. In one, researchers are helping develop NO_x-reducing catalysts in lean engine environments. Another project addresses NO_x absorbers, and another is investigating the use of microwaves to enhance catalyst performance by heating just the surface of the catalyst substrate, where all the reactions take place.

In addition, ORNL provides a facility in which DOE-produced innovations and those from industry can be brought together and evaluated in a realistic engine setting. This "benchmarking" activity is currently using a Volkswagen CIDI engine that was readily available. It will be replaced by higher-technology engines and those from American manufacturers as they become available.

By: Ralph McGill, 423-574-4077, mcgillrn@ornl.gov
Sponsor: Office of Advanced Automotive Technologies

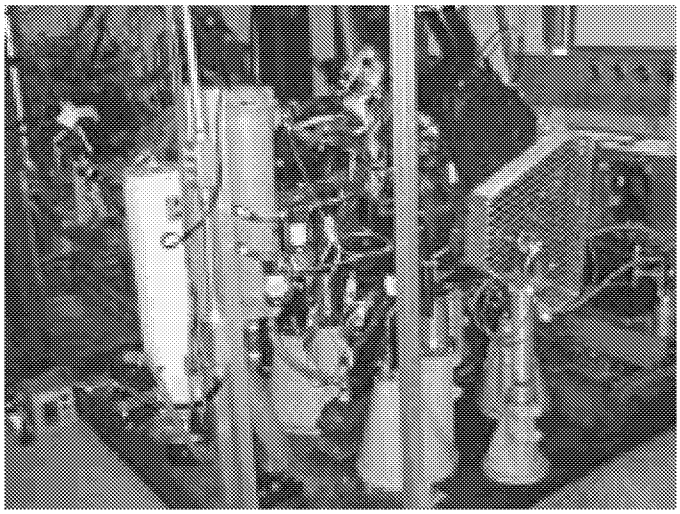
First Complete Emissions and Performance Map (that we know of)

The Advanced Propulsion Technology Center (APTC) at ORNL was recently used to evaluate particulate emissions from an advanced turbocharged direct-injection (TDI) engine over its entire useful speed and torque range. Emissions were characterized at 75 different speed and load points to construct a performance "map" of the engine.

The test appears to be the first characterization of emissions over the entire range of an engine's performance, according to ORNL EE/RE Transportation Program director Richard Ziegler. "There are no data to indicate it's ever been done before."

The light-duty, high-speed 1.9-liter Volkswagen TDI engine that was evaluated is the first modern TDI engine to be certified for use in U.S. passenger cars. Although U.S. automakers are developing small CIDI engines, none has yet produced an engine comparable to the Volkswagen TDI for sale in this country. (American car makers sell CIDI-powered vehicles abroad, but tough emissions standards make the U.S. market more difficult.) To be certified for sale in the United States, CIDI engines must meet stringent emissions standards for oxides of nitrogen, carbon monoxide, particulates, and hydrocarbons when tested over the U.S. Federal Test Procedure driving cycle.

The TDI engine was installed in an engine laboratory in the APTC, where advanced instruments could measure emissions in a very detailed fashion. Especially noteworthy was the measurement of particulate mass and size distribution at each speed and load point. A tapered-element oscillating microbalance was used to allow fast, inexpensive measurement of particulate mass at each point. Previously, collection of sample filters would have been necessary, making the activity much more time consuming. A scanning mobility particle sizer was used to count the number of particles emitted in size ranges from 10 nanometers up to 0.5 microns in diameter.



Volkswagen 1.9-liter CIDI engine installed in ORNL's Advanced Propulsion Technology Center.

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Sponsor: Office of Advanced Automotive Technologies

ORNL's CTA Runs the Numbers on U.S. Transportation Systems

ORNL's Center for Transportation Analysis (CTA) develops and uses advanced computational techniques, analytical methods, and information resources to improve the U.S. transportation system. To accomplish this ambitious goal, the Center staff represent a broad array of science and engineering disciplines, including transportation engineering, geography, and economics; operations research; computation; and other physical and social sciences. CTA's major emphases are

- transportation energy and environment studies
- transportation planning and policy analysis
- transportation data and statistics
- transportation lightweight materials
- intelligent transportation systems
- military transportation logistics

The Center performs studies for the DOE Office of Energy Efficiency and Renewable Energy and Office of Policy, as well as for the Department of Transportation, Department of Defense, and Federal Highway Administration, among others. CTA research for DOE EE/RE includes modeling the energy and environmental trends and implications of transportation systems. These include relationships between travel demands and fuel costs, and the broader implications of alternative fuels costs and market potential. CTA compiles and publishes the definitive *Transportation Energy Data Book* (see accompanying article). CTA's transportation lightweight materials program focuses on studies related to the introduction of new materials and materials processes in automobiles for the Partnership for a New Generation of Vehicles. Studies include the economics of using lightweight materials, such as aluminum and composites, in automobiles; analyzing changes in national infrastructure that might be needed because of the use of new materials; and studying the "recyclability" of vehicles given potential significant shifts to lightweight, high-strength materials.

More information is available at www-cta.ornl.gov.

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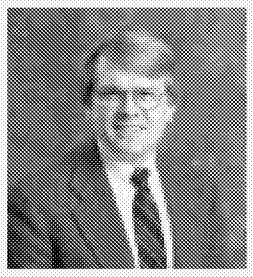
Sponsor: Office of Transportation Technologies

David Greene, a researcher and group leader in CTA, was recently named an ORNL Corporate Fellow in recognition of his outstanding research and leadership. Only 23 researchers at ORNL are Corporate Fellows. Greene's work is directed toward informing public policy on transportation energy use and environmental impacts. He is editor-in-chief of the *Journal of Transportation Statistics* and the author of a book, *Transportation and Energy*, that pulls together most of the essential information and policy-related science in this area.



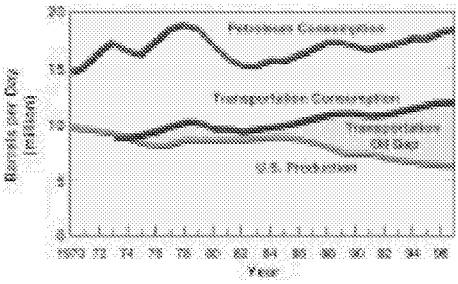
Everything You Ever Needed to Know about Transportation—In One Book

The first *Transportation Energy Conservation Data Book* was developed at ORNL in 1976 in the wake of the energy crisis resulting from the oil embargo imposed by the Organization of Petroleum Exporting Countries. Its major purposes then, as now, were to compile under one cover transportation data from diverse sources, resolve data conflicts and inconsistencies, and produce a comprehensive document.

Designed for use as a desktop reference for policy formulation and evaluation, the *Data Book* is more than 200 pages full of tables and graphs that characterize transportation activity. It emphasizes factors that influence transportation energy use, such as fuel prices and taxes.

The organization and scope of the *Data Book* reflect the need for different kinds of information used by policy makers and analysts, and also reflect the changes in the industry itself. A chapter on alternative fuels was added in edition 11 and a chapter on emissions in edition 14. This year's *Transportation Energy Data Book: Edition 18* has been distributed to some 1000 recipients worldwide in 19 countries. (See www-cta.ornl.gov/publications/tedb.html for the past three editions).

Although the transportation industry has made great strides since 1976, data



Statistics from the latest *Data Book* show the United States is still highly vulnerable to interruptions in oil imports.

from edition 18 of the *Data Book* show that the concern about reliance on imported oil that spurred the first edition is still warranted today. As can be seen from the graph, U.S. petroleum production is down, petroleum imports are up, and transportation consumes an increasing share of the petroleum resources consumed in the U.S.

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Sponsor: Office of Transportation Technologies

ORNL's Research Helps Break Down the Barriers to Hydrogen Power

Hydrogen is regarded by some as the ideal fuel because it is environmentally benign, producing only water vapor as it burns. It can be produced domestically from a variety of renewable resources, including water, plant material, and sewage. If DOE reaches its goal of hydrogen providing 10% of the energy used in the United States by 2025, our dependence on imported oil could be reduced by 50%.

There are substantive technical and economic barriers to widespread use of hydrogen, though. Foremost is the cost of producing it. Today's electrolytically produced hydrogen costs around $30 per million Btu. For comparison, natural gas costs about $3 per million Btu, and gasoline (at $1.10 per gallon) costs about $9 per million Btu. Second is the lack of infrastructure to transport and store hydrogen fuel. ORNL is working with universities, industry, and other national laboratories to break down these barriers and make hydrogen a practical, cost-effective fuel. Hydrogen research at ORNL includes the following projects.

Hydrogen production by photosynthetic water splitting. ORNL researchers are seeking a commercially viable way to produce hydrogen by photosynthetic splitting of water molecules. The potential for producing hydrogen from water-splitting by micro-algae is based on the hydrogen-producing capability of the algae. This capability is based on several factors, including the thermodynamic efficiencies of converting solar energy into the free energy of molecular hydrogen and the potential for using molecular biology and genetic engineering to maximize the efficiency of hydrogen production.

Thermal management technology for hydrogen storage. Absorption and desorption of hydrogen by storage materials require energy transfers to accommodate the heat produced by hydrogenation and activation reactions. Research is under way, therefore, to investigate thermal management technologies for hydrogen storage.

The near-term objective of the effort is to develop physical and heat-transfer computer models to describe hydrogen absorption and desorption in fullerene molecules (hollow, soccer-ball-shaped clusters of carbon atoms) and related materials in order to characterize the behavior of the dynamic storage process.

Thick-film hydrogen sensor detector. Development of efficient hydrogen production, storage, and use technologies will require the capability to detect and pinpoint hydrogen leaks. ORNL is developing a low-cost solid-state hydrogen sensor to provide that capability. ORNL is teaming with DCH Technology, Inc., to develop the sensor for specific market applications related to the use of hydrogen as a fuel.

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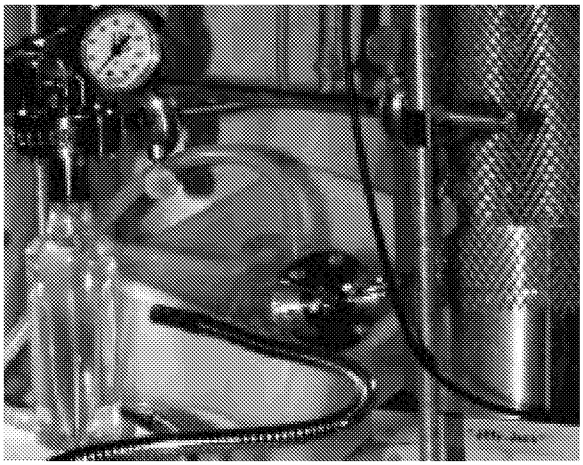
Sponsor: Office of Concentrating Solar Power, Biomass Power, Hydrogen

Scenedesmus Delivers High-Pressure Hydrogen

ORNL researchers have discovered the green alga *Scenedesmus* D_3 can produce hydrogen and oxygen from water at relatively high pressures of hydrogen. The discovery moves DOE/EE's Hydrogen Research Program a step closer to being able to produce hydrogen for fuel via a renewable biological process, rather than by electrolysis.

Scenedesmus D_3 is one of several algae that produce hydrogen and oxygen by splitting water molecules. As hydrogen accumulates in a chamber where the reaction is taking place, the increasing back pressure may block production of additional hydrogen unless the reaction has a strong enough forward "driving pressure" to continue to push molecules of gas through. If the reaction cannot achieve sufficient driving pressure, electrical energy must be used to increase it. The ORNL research demonstrates that the driving pressure of hydrogen production in *Scenedesmus* D_3 is equal to or greater than one atmosphere.

Since it is virtually impossible, in a chamber full of pure hydrogen, to determine the rate of hydrogen production, it was measured indirectly by determining the rate at which the corresponding reaction produced oxygen.



A vial of hydrogen-producing *Scendesmus* algae in an ORNL laboratory setup.

The ORNL research helps to reduce the amount of electrical pumping energy required to deliver hydrogen from a *Scenedesmus* reaction at a usable pressure. In addition, it demonstrates for the first time that the enzyme that causes oxygen to separate from water is insensitive to high concentrations of hydrogen. The enzyme that promotes separation of hydrogen from water, on the other hand, is sensitive to even low concentrations of oxygen.

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Sponsor: Office of Concentrating Solar Power, Biomass Power, Hydrogen

Shaken, Not Stirred: The Recipe for a Fish-Friendly Turbine

Hydroelectric power contributes about 10% of the electricity generated in the United States and nearly 20% of the world's electrical energy. This renewable energy source can help reduce greenhouse gases by offsetting electricity generation using carbon-based fuel. However, rather than growing in importance, hydroelectric generation has actually declined in recent years because of concerns about environmental problems associated with hydropower dams and reservoirs. For many projects in the United States and around the world, these concerns center on (1) restriction of fish passage by the dam and (2) alteration of water quality and river flows by the impoundment.

DOE's Advanced Hydropower Turbine System (AHTS) Program is developing turbine technology to help the world make maximum use of hydropower resources while minimizing adverse environ-mental effects. Its major technical goals are (1) to reduce mortality among turbine-passed fish to 2% or less, compared with current levels ranging up to 30% or more, and (2) to develop aerating turbines to ensure water discharged from reservoirs has a dissolved oxygen concentration of at least 6 mg/L. These advanced, "environmentally friendly" turbines would be suitable both for new hydropower installations and for retrofitting at existing dams.

The initial phases of the AHTS program produced several new turbine designs that are expected to generate electricity efficiently while minimizing damage to fish. However, further development of the turbines is hindered by a lack of information about the sources of injury to turbine-passed fish. The turbine designers need numbers (biological criteria) that define a safety zone for fish within which water pressures, shear forces, turbulence, cavitation, and chance of mechanical strikes are all at acceptable levels for survival.

To supply the needed data, ORNL scientists reviewed the literature on fish responses to the types of biological stresses associated with turbine passage and analyzed the data to develop provisional biological criteria for hydroelectric turbine designers. To fill the gaps in the available information, ORNL scientists are providing technical direction and oversight of shear and water pressure experiments being performed at PNNL.

By: Glenn Cada, 423-574-7320, cadagf@ornl.gov
Sponsor: Office of Geothermal, Superconductivity, Hydropower

Minimizing Stress on Fish Surfing Through Hydropower Turbines

Fish may be exposed to damaging levels of fluid shear stress and turbulence while passing through hydroelectric power plants. It is generally assumed that most such damage occurs in the turbine and draft tube passages, although it is suspected that fish are also injured while passing around the dam, that is, over spillways, sluiceways, and fish bypass outfalls. Unless mitigated, fluid-induced injuries and mortality could frustrate efforts to develop advanced, "fish-friendly" turbines or to provide safe alternate downstream passages.

Unfortunately, the effects of shear stress and turbulence on fish are poorly understood. The challenges include conceptualizing these phenomena, determining their magnitudes and distribution within hydroelectric systems, and then recreating them in a controlled laboratory environment.

ORNL has the primary responsibility for environmental analysis for the Advanced Hydropower Turbine System Program and, as environmental technical monitor, oversees laboratory biological experiments on stresses experienced by turbine-passed fish. Our investigations indicate that the levels of shear stress and turbulence associated with hydroelectric power plants and their reservoirs are either much higher or lower than the levels in free-flowing rivers. Excessively high levels of turbulence may damage or disorient fish; very low levels found in quiet reservoirs may not provide hydraulic cues that fish need to migrate downstream. Most past studies of the effects of shear stress on fish are of limited usefulness, mainly because of their narrow scope and lack of instrumentation to measure velocities on appropriately small temporal and spatial scales.

Consequently, ORNL scientists have developed a laboratory approach for studying the effects of shear stress and turbulence on fish; the laboratory experiments are being done by PNNL under the technical direction and oversight of ORNL and INEEL. ORNL's technical direction and oversight. In addition, ORNL will host a workshop of experts in fluid dynamics to refine our understanding of both the adverse and potentially beneficial effects of turbulence in river systems.

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News Briefs

Don Adams Elected to CPES Committee

Don Adams, a researcher in the Engineering Technology Division at ORNL, has been elected to the executive committee of the Industrial Advisory Board to the Center for Power Electronic Systems (CPES). The election recognizes the quality and caliber of innovative R&D conducted under Adams' leadership in ORNL's Power Electronics and Electric Machinery Research Center. CPES, funded by the National Science Foundation, is working to integrate components of power electronics—devices, circuits, controls, sensors, and actuators—into modular systems that can be customized for industrial applications.

Energy Programs at ORNL Available

The document *Energy Programs at Oak Ridge National Laboratory* (ORNL-6946) was published recently by ORNL. It provides a broad view of ORNL's work since 1993 in energy efficiency and renewable energy, fission energy, fossil energy, and fusion energy. An introductory chapter provides summaries of the work in these areas; an overview of Laboratory programs in sustainable energy, fundamental science and technology, environmental programs, and energy policy and information; and a timeline of sustainable energy activities from 1943 to the present. Call Jean Bray at 423-576-2325 for more information.

EE/RE at the Expo

ORNL's EE/RE Program supported and participated in the Tennessee Energy and Environmental Expo held in May at Middle Tennessee State University (MTSU). The Expo showcased the new MTSU Center for Energy Efficiency that is led by Joe Whitefield, formerly of ORNL. The conference emphasized efficiency in public buildings, with sessions on all aspects of performance contracting. Mike McDonald and Anthony Wright delivered presentations. Dave Jamison set up and staffed an ORNL EE/RE booth.

Tom Gross Visits ORNL

Tom Gross, DOE's Deputy Assistant Secretary for Transportation Technologies, attended the groundbreaking ceremony for the National Transportation Research Center in April. DOE's contributions to the Center include the scientific and technical capabilities of ORNL and a funding base of about $45 million in transportation R&D. In addition, the Center will be home to about $40 million in R&D projects from other agencies, primarily the Departments of Transportation and Defense.

Gross also toured ORNL facilities where some of the work funded through OTT is done. He viewed the recently acquired IBM RS/6000 SP supercomputer, which will be configured to perform a trillion operations per second. The machine will enable engineering simulation activities aimed at developing advanced transportation vehicles and alternative fuel technologies.

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