Science & Technology HIGHLIGHTS

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"Oscars of Invention" for EE/RE Reach Sweet 16

This issue celebrates our R&D 100 award winners. Presented annually by *R&D Magazine*, these awards have been called "The Oscars of Invention" by the *Chicago Tribune*. In 1999, the ORNL Energy Efficiency and Renewable Energy Program received three R&D 100s, bringing our total to 16 since the program was established in the late 1970s. Our three latest winners are showcased in articles spread through the following pages.

The commercial adoption of these "Oscar winners" is a goal of our program. While some of our winners have been incorporated into manufacturing processes and systems, others have fallen by the wayside. Some have become the foundations of new companies, providing new jobs and economic growth. Overcoming the many barriers to commercialization can be a long road. According to Larry Dickens, Head of Technology Licensing for ORNL, the time to commercialization for an advanced material can be 10 years or more. A process or new type of instrument or equipment, however, may hit the market within a few years.

Here is a brief look at three of our past winners that are seeing vastly different commercialization paths: a new twist on an existing piece of equipment, an advanced material, and a new industrial process.

A winner on the commercialization fast track is the **Variable Frequency Microwave Furnace (1997).** Researchers created a microwave furnace that can vary its frequency output, eliminating hot and cold spots in the furnace cavity. This special microwave can also pinpoint frequencies that are best absorbed by specific materials. Lambda Technologies fabricated the traveling-wave tube for ORNL's research prototype; the company subsequently licensed the technology and is marketing the variable frequency microwave furnace for use in polymer and adhesive curing.

An advanced material that is just now beginning to see commercial use is **Nickel Aluminide (1983).** Nickel aluminide (NiAL) has a unique structure that has excellent resistance to oxidation and carburization at very high temperatures, perfect for use in heat treating furnaces, steelmaking, and other manufacturing processes. The alloy was difficult to make, so commercialization was hindered until the mid-1990s, when an ORNL researcher discovered a production process that he named Exomelt. Itself an R&D 100 winner, **Exomelt (1995)** addressed the cost and safety concerns in making NiAl. Since then, NiAl transfer rolls and furnace trays have been in use for several years without signs of deterioration, and forging dies made of NiAl have demonstrated a production life 10 times longer than that of conventional dies.

Metal Compression Forming (1997) is an alternative to traditional metal casting processes. It consistently produces parts with fewer defects and with properties comparable to those of forged pieces. Metal compression forming has been proven with simple production parts. We are now working with a small business to produce more complex parts; our partner hopes to increase its customer base using the new process.

Our 1999 R&D 100 winners are spotlighted in this issue. Look for the R&D 100s logo.

ORNL research scientist Srinath Viswanathan examines a motor mount produced by metal compression forming.

Roofing Research Battles Roof Failures Caused by Water and Wind

Roofing failure, whether a dramatic rip-off during a hurricane or gradual deterioration due to undetected leaks, is costly and disruptive. The Roofing Research Program of ORNL's Buildings Technology Center (BTC) is helping prevent premature roof failures caused by either wind or water.

Commercial roofing in the United States costs consumers and building owners $18 billion per year. A roof lasts about 12 years on average; the roof will be replaced three or four times during the life of a typical building. The need for multiple roofs makes roofing one of the largest contributors of solid waste.

BTC research scientist Achilles Karagiozis measures moisture levels in a roof damaged by moisture intrusion.

The principal causes of premature roof failure are moisture intrusion and lack of wind resistance. Moisture accumulation in roofing systems leads to dripping, accelerated failure of the insulation and membrane, roof structure deterioration, depreciation of assets, and poor thermal performance. Similarly, the loss of a roof during a major windstorm not only causes structural damage, but also exposes the building contents to the elements. The insurance industry identifies roofing as the primary contributor to disaster-related insured losses.

The Roofing Research Program has teamed up with the roofing industry to perform research in these two critical areas with the dual goals of extending roof service life and improving energy efficiency.

Research is under way that will help roofing system designers make roof configurations more moisture-tolerant. A designer who understands how characteristics of a roof impact moisture movement can select the components that are appropriate for a particular building in a specific climate. The proper design can eliminate or minimize the potential for moisture-related problems such as condensation. The BTC's "Moisture Calculator" (www.ornl.gov/roofs+walls) simplifies the design process. The algorithms in the calculator were developed using a computer model validated by laboratory and full-scale field experiments.

The BTC is also collaborating with more than 75 private companies to investigate roof-related damage from major windstorms such as hurricanes. After major wind events, 35-person teams are sent out to assess wind damage to roofs. This study will yield a better understanding of what causes roofs to survive or fail in high winds, leading to improvements in roof system durability and reduced overall costs for the public.

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Nailing Down the Energy Savings from Cool Roofs

Wear white clothing on a clear hot summer day and you're cooler than someone wearing dark clothing. Light colors reflect more of the sun's heat, while dark colors absorb it. Similarly, light-colored roofing materials reflect the sun's energy. A light-colored roof will have a significantly lower temperature than a dark one and therefore can reduce the amount of energy used by a building in a warm climate. In urban areas, large numbers of reflective roofs can reduce the outside air temperature, saving even more energy and improving air quality by lessening the effect of urban heat islands.

Despite the simplicity of the cool roof concept, tests performed by several different research organizations under widely varying conditions are confusing industry, regulators, and consumers. They do not know how to evaluate marketing claims or decide how test data apply to their situations.

The BTC has initiated three industry-cosponsored research projects to quantify the energy savings potential of cool roofing systems. With nearly 80% of the roofing industry participating, we are conducting systematic side-by-side exposure studies of roof coatings, membranes, and metal roofing systems to assess their long-term performance. The BTC will use this experimental database to develop and validate computer models that consumers can use to estimate the energy savings they would enjoy by selecting a cool roof.

BTC researchers Bill Miller (kneeling) and Jerry Atchley measure the solar reflectance (percentage of solar energy in the visible range that is reflected) of residential roofing systems on a test building at ORNL.

Frostless Heat Pump Keeps the Inside Air Warm

One of the drawbacks consumers cite for heat pumps is the low temperature of the air supplied and the occasional blasts of noticeably colder air when the outdoor coil defrosts. Heat pumps save money on utility bills, compared with other types of electric-heating equipment, and they're a lot more energy-efficient. But homeowners hate that cold air!

Thanks to ORNL, warmer air (along with more reliable heat pump operation) is on the way. A technology developed by engineers in the Buildings Technology Center, the "frostless heat pump," has been shown to retard the formation of frost on the heat pump's outdoor coil. Doing away with the frost would eliminate most defrost cycles and warm up the supply air. In recognition of the welcome step forward for chilly homeowners, *R&D Magazine* gave the innovation a 1999 R&D 100 award.

A heat pump's outdoor heat exchanger coil sometimes frosts over when outdoor temperatures fall to between 40 and 30°F (at less than 30°F, air usually contains little moisture to form frost). The frost interferes with heat absorption, so the coil must be defrosted. To do so, the heat pump temporarily reverses itself, taking heat from the house and pumping it to the coil. To compensate for the heat loss, most systems turn on resistance-heating elements. But even with those going (and causing power surges), the air coming from the registers temporarily blows noticeably cooler.

The frostless heat pump addresses the problem mainly by adding heat to the heat pump's accumulator. This increases heating capacity because most of the heat added to the accumulator is transferred to the indoor heat exchanger. Basically, that means the heat pump can satisfy the house heating load before the coil frosts up. The temperature of refrigerant entering the outdoor coil also is increased by 4 to 6°, retarding frost formation. When frost does form, the heat pump melts it using heat from the accumulator instead of redirecting heat from the air supply for the indoors.

The frostless heat pump has several advantages, including increased reliability and reduced power surges from cycling on and off. But the benefit consumers appreciate the most may be the steady supply of warm air.

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Sponsors: Tennessee Valley Authority, DOE/BTS Office of Building Research and Standards

The frostless heat pump developed by BTC researchers (from left) Rick Murphy, Fang Chen, Ron Domitrovic, and Vince Mei eliminates most heat pump defrosting cycles.

Heat Pumps Squeeze the Heat From "Cold" Air

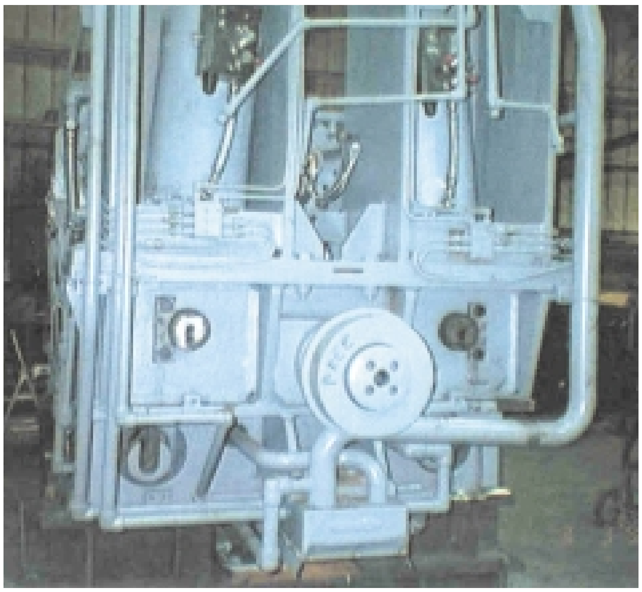
Although it is hard to believe, heat pumps use air that feels cold to us to warm our homes. To do so, they capture the ambient heat in "cold" air (or water or soil), increase it, and transfer it to the air that comes out of the duct system. (All substances above absolute zero temperature contain heat; even air at 0°F contains nearly 90% of the heat it contains at 70°F.)

A heat pump is efficient because it uses a process that consumes less energy than warming air in a furnace. A heat pump acts as an energy multiplier. For example, a typical heat pump absorbing heat from a source at 47°F and maintaining indoor air at 70°F produces 3.3 to 3.6 units of useful heat for each unit of electrical energy it consumes. A traditional gas or oil furnace delivers less than 1 unit of heat for every unit of energy used. So how does a heat pump heat so efficiently?

Residential heat pumps typically employ a vapor compression cycle. They use a refrigerant, which absorbs and releases heat in changing from liquid to gas and back. In a heating mode, cold refrigerant liquid and vapor flow through an outdoor heat exchanger. Because the refrigerant is colder than the outside air, it absorbs heat from it. That heat evaporates all the liquid into vapor. The vapor then is sucked into a compressor and compressed into a high-pressure gas. Compression raises the temperature of the vapor significantly. Now this warm vapor enters an indoor heat exchanger and transfers its heat to air circulating inside the house. The heated air recirculates to the living space to warm it. The refrigerant vapor, now cooler, condenses into a high-pressure liquid and flows through a pressure-reducing valve, which causes it to vaporize partially and cool further. The liquid/gas mixture is fed back into the outdoor heat exchanger to start the cycle again. (In cooling mode, the cycle is reversed, but that's another story.)

Increasing Productivity, Reducing Waste in Steel Manufacturing

Steel manufacturing is one of nine energy-intensive industries with which DOE's Office of Industrial Technologies has initiated research partnerships to work toward more energy-efficient manufacturing. ORNL researchers collaborate with the industry through a focused research program that draws on the multidisciplinary expertise of several ORNL research divisions. It has resulted in several technologies that enhance productivity and reduce waste in steel making, including an R&D 100 winner, galvanneal temperature measurement using fluorescence-based thermography (see related article on p. 5). Other successful or promising collaborations include these:



This caster from a steel casting line is being instrumented with sensors that will provide data for value chain analysis.

- Development and performance testing of cost-effective, energy-efficient steel framing systems for houses, in cooperation with the National Association of Home Builders.
- Development of high-temperature intermetallic alloys for the steel industry. Transfer rolls are being used at Bethlehem Steel with excellent results to date.
- Creation of a neural network model to control laser-assisted arc welding (LAAW). LAAW combines arc welding and laser welding to exploit the advantages (and eliminate the weaknesses) of both processes.
- The use of value-chain analysis to estimate the "value" of a technology to industry in terms of energy, cost savings, and productivity (see accompanying article).
- A study of deformation behavior of lightweight steel structures in automobiles.

ORNL played a leadership role in developing a Memorandum of Cooperation between the American Iron and Steel Institute, the Steel Manufacturers Association, and DOE. The agreement, signed in 1999, provides a framework for steel industry companies and DOE laboratories to use in establishing joint efforts to translate the steel industry's vision of its future into reality. For more information, see www.oit.doe.gov/steel/.

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Value Chain Analysis: Helping Companies Profit from Change

Today's manufacturing systems and equipment must perform at levels thought impossible a decade ago. Companies must push operations, quality, and efficiencies to unprecedented levels while holding down costs. The steel industry is a prime example of companies forced to adapt constantly and rapidly as customers' needs and product mixes evolve.

The survival and ultimate success of American steel companies will depend on their ability to innovate quickly and assess the impact of the changes. Given the need for flexibility, companies need methods to predict and measure how new technologies and strategies will affect overall plant performance.

To meet that need, a team led by ORNL's Instrumentation and Controls Division has developed a tool called value chain analysis. It can estimate the value of a technology in terms of energy use, cost savings, and additional production. Value chain analysis is a derivative of an enterprise model in that it calculates the added value of a technology to a particular subsystem, but not necessarily to the entire process.

There are four basic steps to conducting a value chain analysis: (1) develop a functional description and understanding of the selected process, (2) define measures of performance and economic indices that are defensible, (3) define the physical attributes of the process that need to be controlled and observed, and (4) through the process and functional links, determine overall plant impacts.

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Expected benefits of value chain analysis

- **Reduced operating and support and life-cycle costs through a better understanding of technology impacts**
- **Energy and waste stream reductions**
- **Identification of technologies that are cost-sensitive to infrastructure**
- **Defensible technology selection**
- **Ability to map technology needs onto functional requirements**

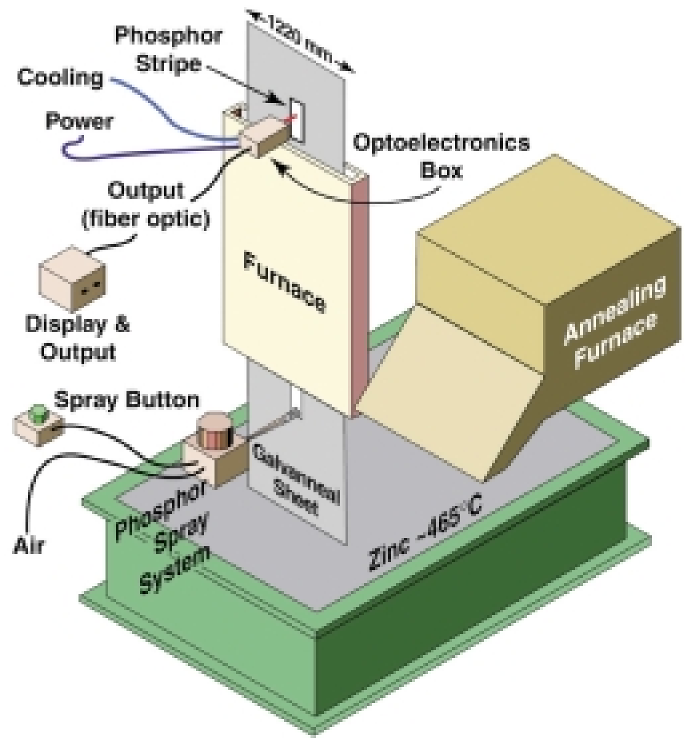
Measuring Steel Processing Temperatures in Real Time

The galvanneal temperature measurement system (GTMS), one of ORNL's 1999 R&D 100 award winners, is the first measurement process capable of measuring steel process temperatures accurately in real time. It provides temperature data that enable plant operators to adjust temperatures throughout the galvanneal process, protecting the quality of the product and reducing waste.

Galvannealing forms a rust-resistant coating on sheet steel. While the process is under way, the steel sheet passes through a bath of liquid zinc and then through a cascade of furnaces. If the temperature is maintained correctly, the zinc mixes with the iron at the surface of the sheet, forming a rust-resistant alloy. If the proper temperature is not maintained, however, product quality can vary, a problem that costs the steel industry millions of dollars annually. Before the GTMS was developed, process temperatures could not be measured precisely.

The shortcoming of the conventional method is that it assumes surface properties are constant, says ORNL's Steve Allison. Actually, the properties of the zinc-covered surface rapidly change as the coated steel cools from molten to solid, causing errors of as much as 40°C when temperatures are measured with conventional sensors. The GTMS is accurate to within less than 3°C.

The system is noninvasive. First, a computerized deposition system applies a white phosphor powder to the steel sheet. Then, as the sheet travels between the furnaces, a low-power nitrogen laser fires short pulses of ultraviolet light through an optical fiber leading to the phosphor-treated surface. The laser pulses excite the phosphor, which emits light briefly. The emitted light travels via another optical fiber to a light detector, which measures the time for the phosphorescence to decay. A computer calculates the surface temperature from the data. Operators then make adjustments in real time to compensate for any temperature variance.



The GTMS allows precise measurement of steel process temperatures.

The GTMS was demonstrated successfully for the first time in May 1998 at the Bethlehem Steel plant in Portage, Indiana. It was developed by a team from ORNL and the University of Tennessee, Knoxville, in collaboration with National Steel.

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I&C Laboratories Specialize in Sensing and Measurement Problems

The work of ORNL's Instrumentation and Controls (I&C) laboratories ranges from basic R&D to design, fabrication, installation, and maintenance of one-of-a-kind devices and systems. The I&C's labs core capabilities are in systems integration, photonics, custom electronics, signal processing, sensors, and controls and simulation.

Systems integration grows out of I&C's work in designing, assembling, and testing at the systems level. Large projects often require integrating diverse technologies and manufacturers to ensure capable and working systems the first time.

Photonics capabilities include R&D in optical materials, environmental sensing, analytical instrumentation, electro-optics, lasers, and physical measurements. I&C's expertise is supported by research conducted across ORNL and by the precision manufacturing facilities of the Y-12 Plant in Oak Ridge.

Custom electronics R&D covers every area of circuit development, design, fabrication, packaging, and testing. The I&C laboratories have unique capabilities in microelectronics and application-specific integrated circuits, radio-frequency and microwave frequency devices, digital architecture development, and sensor-electronics integration.

Signal processing capabilities include both fast Fourier and wavelet transform technologies. Digital signal processing in the I&C laboratories pushes the processing speed envelope at 23 gigaflops in real time. Our image processing capabilities combine signal processing and photonics expertise to allow real-time detection and classification of features and flaws in manufacturing processes.

Sensor technologies and expertise are available to measure or observe virtually all physical, chemical, and biological

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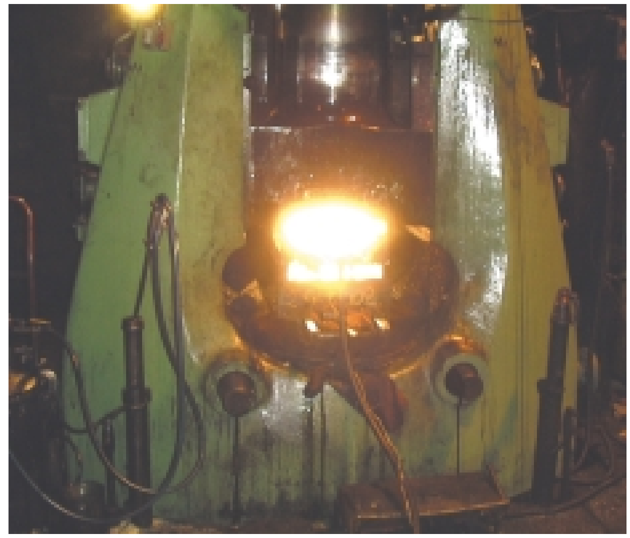
Infrared Heating Saves Industries Energy, Time, and Money



Infrared insert heater preheating dies at Komtek, in Worchester, MA, prior to their use to forge medical hip implants.

High-density infrared heating—a fast, precise method of heating metals and other materials that has been under development at ORNL for several years—is proving highly successful in field tests in industrial facilities. Infrared processes are energy-efficient, effective, safe, and environmentally friendly, and they can bring significant cost savings.

ORNL has established an Infrared Processing Center that offers its users access to a variety of infrared heat-treatment systems. Infrared processing employs tungsten halogen lamps, stabilized plasma systems (the most powerful lamps in the world), and lasers. The heating systems can be devised in a variety of furnace shapes—simple unidirectional or bi-directional panels, box or tube furnaces, spot and line heaters, or systems for inner-diameter heating. The plasma-based systems can be used in a scanning mode with robotics at widths as large as 15 inches.

Infrared technologies have several advantages over conventional heating methods (gas-fueled, resistance, induction, and microwave). Infrared heating is a clean, noncontact process that ramps to full power in milliseconds and shuts down instantaneously. Precise, controllable heat fluxes allow rapid heating (i.e., 50 to 400°C per second and higher) and "zone" heating. Because only the sample is heated, cooling is rapid. High heat fluxes can be delivered unidirectionally over a large area, allowing control of temperature gradients through thick sections. The shape of the material to be heated does not limit the process, and it couples with most materials.

Infrared boot heater being used at Delphi Automotive.

Infrared processes have been developed at ORNL for a variety of applications including joining, preheating, coating consolidation, stress relieving, and composite fabrication.

ORNL has worked with several industrial partners to develop successful infrared processing applications. Delphi Automotive Steering Systems in Athens, Alabama, recently installed six single and two double heat zone infrared boot heaters developed by ORNL. They heat thermoplastic and polymer boots that will be placed on auto components such as steering assemblies and CV joints. The infrared units heat and expand the boots in 4 to 5 seconds, virtually eliminating the force formerly required to install the components. The heating and subsequent cooling of the boot results in a better seal than when boots are forced on without being heated. The response from assembly line employees who have used the product has been extremely positive. In many cases, ergonomic problems have virtually been eliminated and production has increased.

An infrared die insert heater fabricated by ORNL has shown outstanding results in field tests for robustness, die life extension, and energy savings. Steel dies used in custom forging and die casting must be preheated to 600°F before being used. Preheating with conventional gas or electric calrod heaters takes up to 4 hours, and gas heating can cause die degradation if it is not done properly. ORNL's infrared heater can preheat dies in less than 10 minutes. It converts electric energy to infrared energy at more than 90% efficiency, almost twice that of commonly used electric calrod-type heaters.

A serious problem in the die casting industry is degradation of the tooling used in the process. ORNL has developed coatings and coating processes using high-density infrared that have already increased die tooling life by an order of magnitude. Further research should enable us to extend tool life by an additional order of magnitude, or 100 times. This advance will substantially decrease energy consumption for remanufacturing of tooling and decrease manufacturing cost by eliminating equipment down time.

The custom forging and die casting sectors of the forging industry together provide about 1.1 million jobs and contribute more than $13 billion to the U.S. economy annually. Parts produced by forging and die casting are used in applications ranging from automotive, agricultural, industrial, and aerospace equipment to computers and medical implants. Infrared processing promises substantial reductions in energy use and manufacturing costs for these key industries.

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Sponsors: Office of Advanced Automotive Technologies and Office of Industrial Crosscut Technologies

Red-Hot Research at the Thermophysical Properties User Center

The Thermophysical Properties User Center (TPUC) in the High Temperature Materials Laboratory is home to the expertise and facilities used in ORNL's research on braking systems and a variety of other research efforts associated with thermal conductivity.

TPUC facilities are a resource for studying the characteristics (e.g., thermal stability, thermal expansion, thermal conductivity) of materials as a function of temperature and/or environment. Its instruments can characterize the thermal properties of materials as bulk specimens, coatings, or thin films. The thermophysical properties of metals can be measured from above the melting point down to room temperature.

The TPUC houses several unique instruments. For example, a high-speed, high-sensitivity infrared camera has been used to map temperatures for processes such as lost foam casting and glass forming, obtain thermal diffusivity maps of composites, nondestructively detect subsurface flaws, and capture the thermal elastic instabilities in brake rotors (see accompanying article). The exposure time for each image can be adjusted down to two microseconds, allowing the study of extremely hot and/or fast moving targets.

Another one-of-a-kind resource is a laser-flash diffusivity system, made up of four furnaces, that supplies data on thermal transport. The most advanced of the furnaces—a quench furnace—uses a focused light beam to heat a material rapidly up to 1000°C, then blasts the sample with liquid helium to cool it by 200°C per second. The process allows users to cool a material to a certain temperature and hold it there to gather data on its properties at that temperature.

The staff working with the TPUC are continually developing new instruments to study materials ranging from textiles to alloys. Not only the sophisticated instruments, but also the expertise of the researchers who staff the center make it a valuable resource for industry. Small industrial users who could not afford either the sophisticated instruments or a large research group can send staff to the TPUC to learn to operate the instruments and use the data to improve their products.

For more information on TPUC resources and/or on using the facilities, check http://htm29.ms.ornl.gov/tpuc/index.html.

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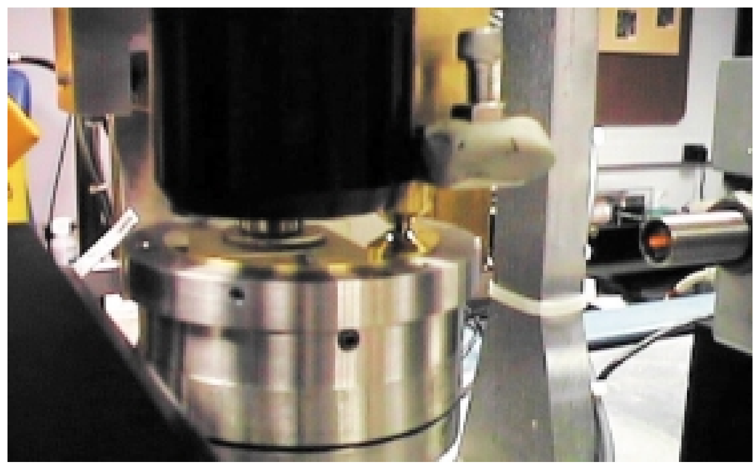
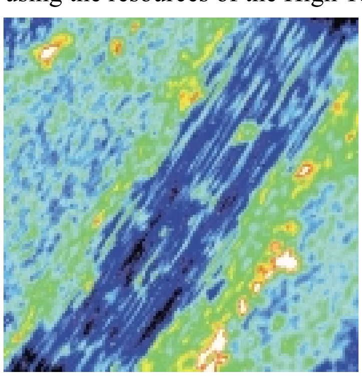


Close-up view of a high-speed infrared microscope (left of center) aimed at a tiny spot on the contact surface of a flat disc sliding against a steel bearing (center).

ORNL R&D—Bringing You Better Brakes

Since the early 1990s, ORNL has contributed to R&D efforts aimed at improved braking systems and materials for autos and trucks. They include projects analyzing the characteristics of existing brake materials, as well as exploring the use of advanced materials for a new generation of brakes.

Research staff from Ford Motor Company have joined ORNL researchers on several projects. These range from an effort using the resources of the High Temperature Materials Laboratory (HTML) to measure the thermal diffusivity of cast iron rotor materials, to a year-long CRADA to study the effects of brake pad additive compounds on the frictional stability of brakes under wet and dry conditions. In addition, under the direction of ORNL's Camden Hubbard, neutron diffraction facilities were used to measure through-thickness residual stress distribution in brake disks.



One in a sequence of images of a worn area of an oxidized disc. Such infrared images can help reveal details of brake pad and rotor wear.

Cooperative projects have also made use of infrared imaging to assist in validating theoretical models of "hot-spot" formation on brake rotors. HTML's infrared camera was used to make the first actual temperature maps of the hot spots that result in undesirable vibrations. Understanding the thermal instabilities in rotor materials that cause the problem is a step toward designing more stress-resistant brakes.

Under the sponsorship of the ORNL Laboratory-Directed Research and Development Program, ORNL scientists Peter Blau and Ralph Dinwiddie have developed a novel microscopic imaging technique called "micro-tribothermography" that enables researchers to use high-speed infrared microscopy to study how wear surfaces change with time. The technique can produce "movies" showing the fine details of material degradation on frictional surfaces like those in car and truck brakes.

In August 1999, HTML staff organized and conducted a DOE /ORNL workshop to identify future needs for brake

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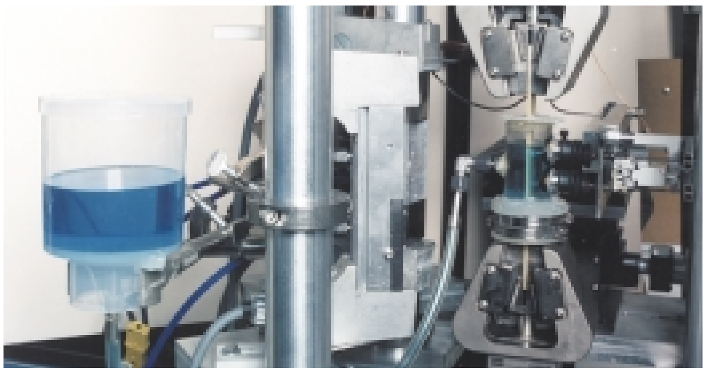
Survival of the Fittest: Testing the Durability of Composites

A major impediment to the widespread use of composite materials in auto manufacturing is a lack of data to ensure the long-term integrity and durability of structures built with composites. ORNL researchers are devising and conducting tests for composites under simulated on-road conditions to aid in developing guidelines for use by auto designers.

ORNL is working closely with the Automotive Composites Consortium (ACC) to design and carry out laboratory tests that measure the effects of various conditions and events on structural strength, stiffness, and dimensional stability. Durability issues being considered include the potentially degrading effects of both periodic and long-term sustained loads, exposure to various automotive fluids and environments, temperature extremes, and impacts from such events as dropped tools and roadway kickups.



A composite specimen, mounted in the grips of a test machine, undergoes cyclic fatigue loading while immersed in windshield washer fluid (an extreme condition). This is one of a battery of tests imposed on candidate composites.

In the first phase of the project, two representative random-glass-fiber composites, chosen and provided by ACC, were tested. The first material employed continuous swirled strands of fiber reinforcement. The second used chopped-glass fiber and closely resembles the material used in the pickup truck box discussed in the accompanying article. Based on the ORNL testing, an extensive durability database was generated for each material and design criteria documents were developed. Each of the three auto maker members of ACC is using these criteria for individual proprietary applications in vehicles. The durability test protocol that was established by the ORNL research also has been documented. Together, these documents provide a framework for auto makers and their suppliers to characterize the durability of future glass-fiber composites.

The current focus of the ORNL effort is a series of carbon-fiber composites with different reinforcement configurations, ranging from highly oriented to randomly oriented fibers. These composites raise new challenges in addition to the durability issues associated with the random-glass-fiber composites. The research goal is durability-based design criteria and a test protocol similar to those developed for the other composites.

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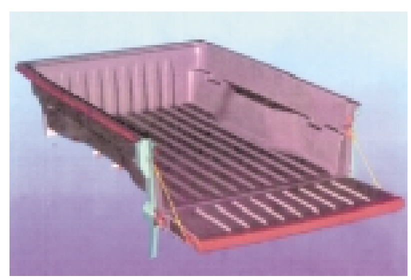
High Carbon Fiber Content Helps Vehicles Shed Pounds

The Lightweight Vehicle Systems Materials (LVM) program, jointly managed by DOE and the United States Automotive Materials Partnership, develops materials and processes for fabricating lightweight structural vehicle components. ORNL is the technical lead for the R&D effort between DOE and the Automotive Composites Consortium (ACC).

Research in the first phase of the LVM program focused on developing technologies to make glass-reinforced composites technically and commercially viable. In cooperation with the ACC, those technologies were integrated into a manufacturability demonstration project: a pick-up truck box 25% lighter than its steel counterpart, adhesively bonded to the frame, manufactured at a rate of 15 parts per hour, and meeting all durability requirements, at no cost penalty to the consumer. Some of the technologies developed under this program are being incorporated into year-2000 production vehicles.

The current research focus is on making carbon-fiber-based components commercially and technically viable. In addition to the technical obstacles facing other composites, the high cost of reinforcing fibers is a disadvantage for carbon fiber materials. Researchers are seeking ways to reduce fiber prices by developing non-traditional precursors, improving precursor processing technologies, and developing new production technologies.



This pickup truck box is made of glass-reinforced composite.

Manufacturability. We are developing high-rate preforming techniques that use dry spray-up to obtain chopped-fiber preforms of consistent fiber densities at the volumes required by industry. Technologies under study for high-volume production of composite materials include high-volume injection molding, injection compression molding, net-shape forming, thermoplastic thermoforming, resin transfer molding, and automated material handling systems.

Design data and test methodologies. A knowledge base is being built for assessing the effects of impact, creep, fatigue, automotive fluids, temperature extremes and other influences on

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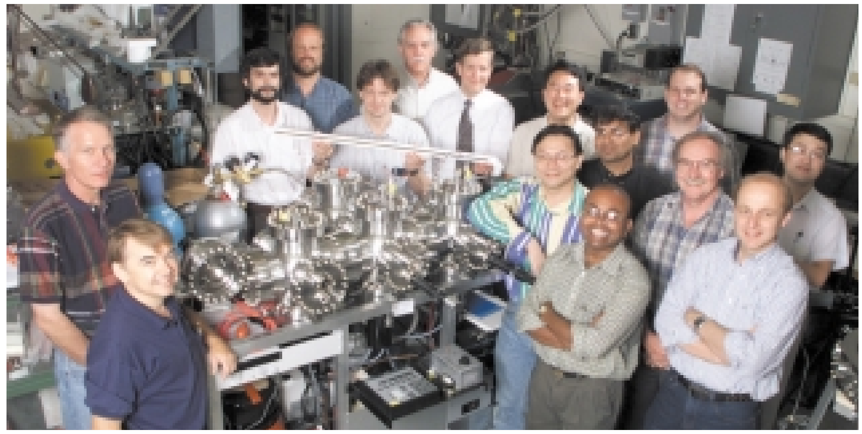
RABiTS: Substrate is the Backbone of Superconducting Wire



The ORNL RABiTS team displays a specimen of its prize-winning substrate.

Since it was first demonstrated in the mid-1980s, high-temperature superconductivity has encountered obstacles to practical application. The Rolling-Assisted Biaxially Textured Substrate (RABiTS) process, winner of a 1999 R&D 100 award, overcomes several of those obstacles. RABiTS was created through a multidisciplinary effort at ORNL to develop superconducting wires and applications for electrical power.

Superconductors are remarkably efficient. In laboratory experiments, superconducting materials have transmitted hundreds of times the current density (amps per square centimeter) that ordinary household copper wire can handle. Moreover, they can transmit electricity with virtually no losses due to resistance.

High-temperature superconductors are produced in kilometer lengths by many companies. However, to be used in most electrical power applications, which employ magnetic fields, these first-generation wires must be operated at temperatures of about 20 to 30 K, attainable only by surrounding them with helium gas. RABiTS helped overcome the limitations in using a yttrium compound as the superconductor, which works much better in the presence of magnetic fields in a bath of liquid nitrogen (77 K) instead of gaseous helium.

ORNL's big challenge has been to fabricate wires and tapes coated with properly aligned yttrium-barium-copper oxide (YBCO). RABiTS is the template upon which the YBCO is deposited. It is made from roll-textured and annealed metals, such as nickel or nickel alloys, and one or more ceramic buffer layers. The superconducting YBCO is deposited on this template using a variety of techniques. The highest-performing short samples of RABiTS-based superconducting wire can carry 3 million amps per square centimeter at 77 K.

Their length, flexibility, comparatively low cost, and carrying capacities make RABiTS substrates ideal for high-temperature superconducting wires. Further development of the RABiTS process could lead to many industrial or commercial applications of superconductivity where none presently exist.

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Pulling Awards Out of a Hat

The R&D 100 award is not the only indication of the potential of the RABiTS technology. Honors, awards, and—more significant for its ultimate usefulness—deals to develop the technology for the marketplace have multiplied like . . . well, you know.

The process and its inventors have received numerous recognitions. RABiTS was a winner in the "Emerging Technologies" category of the 1999 American Museum of Science and Energy Awards—Tribute to Tennessee Technology.

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Amit Goyal, Top Young Innovator

Amit Goyal

Amit Goyal, a member of the ORNL team that developed RABiTS, was recognized recently as one of the people with the most potential to contribute to technological innovation in the next century by *Technology Review*, a magazine published by the Massachusetts Institute of Technology (MIT).

The members of *Technology Review*'s "TR100: 100 Top Young Innovators" were announced at a ceremony at MIT in November. In making up the list, the judges concentrated on cutting-edge technologies, particularly biotechnology, chemistry and materials science, and information technology. Candidates had to be under 35, and emphasis was placed on "those who are innovators to watch . . . whose greatest and most exciting efforts lie in front of them."

It's intriguing to think of Goyal's best work being ahead of him, given the achievements already behind him. His work with RABiTS and other high-temperature superconductivity technologies earned, just in 1999, awards for ORNL Inventor of the Year, R&D Sustained Development; R&D Significant Development, and World-Class Teamwork, and an Inventors Forum Patent Acorn. He is an inventor on seven issued U.S. patents, along with 15 more U.S. and several foreign patents pending. He is the author of more than 130 articles in national and international journals and conference proceedings. He serves on the advisory board for the Materials Research Science and Engineering Center of Excellence at Carnegie Mellon University and is vice-president of the East Tennessee chapter of the Materials Research Society.

High-Temp Superconducting Cables are Up and Testing

For the past year, Southwire Company has been installing the world's first real-world application of a high-temperature superconducting (HTS) cable system at its headquarters in Carrollton, Ga. Three 30-m cables will power three of the company's manufacturing plants, marking the first time a company has successfully made the difficult transition from laboratory to practical field application of HTS cable.

ORNL has assisted Southwire with the overall cable system design, including the cryogenic system and cable terminations, laboratory testing, and field testing of cables. The cables were delivering power to the plants during short testing periods—several hours at a time—in January 2000; plans were to place them into continuous service in February.

HTS cables cooled to 77 K are being demonstrated and will soon be carrying at least three to five times more current than conventional cables through the existing underground pipes. This offers strategic benefits to utilities and a cost-effective means for repowering the existing electricity delivery infrastructure.

For the past four years, ORNL has been working with Southwire to develop a superconducting power cable. Initially, superconducting tape made from bismuth strontium calcium copper oxide ($BSCCO_{2223}$) was tested at ORNL to gain a better understanding of the material characteristics as they pertain to making a cable. Then Southwire made several 1-m prototype cables that were tested at ORNL to verify differing conductor designs.

In FYs 1998 and 1999, Southwire and ORNL jointly designed, constructed, and rigorously tested two 5-m superconducting cables and all subsystems in an ORNL laboratory. The cables were capable of carrying 1,400 amps, exceeding the design goal and demonstrating stable operation at design parameters of 7.2 kV ac and 1250 amps and 77 K. At the same time, a facility was built to test the performance and longevity of the cable's electrical insulation system. Model cable tests were conducted in FY 1999 using 1-m cables to simulate the construction of the electrical insulation system of the actual cable.

The project at ORNL is directed by the Superconductivity Program for Electric Power Systems and funded as part of the DOE Superconductivity Partnership Initiative. Based upon the success to date, Southwire and ORNL are already discussing future uses of the superconducting cable with several U.S. utility companies.

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The world's first field test of an HTS power delivery system will deliver power to three plants at the Southwire facilities.

Other RABiTS Awards

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The RABiTS team also won a World Class Teamwork Award in 1999 and a Lockheed Martin NOVA Award for technical achievement in 1997. Amit Goyal, a RABiTS team member, has been named a "Top Young Innovator" largely for his work on the project (see article on p. 9).

A coil of superconducting cable built on RABiTS.

Seven U.S. patents have been granted for technologies that are RABiTS progeny, three in 1998 and four during the last quarter of 1999. Several RABiTS-based invention disclosures also have been filed recently.

A number of companies have joined in CRADAs and licensing agreements with ORNL to develop RABiTS for commercial purposes. In each case, ORNL is a participant in a supporting CRADA involving the licensees. A key distinguishing feature of the CRADAs is that each of the individual partners has chosen a different method of depositing the superconductor on RABiTS. ORNL is also working with American Superconductor Corporation on aspects of superconducting wire development.

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Value Chain Analysis

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The ORNL-led team recently conducted a value chain analysis at the NUCOR Berkeley Plant, in Mt. Pleasant, South Carolina. They began by constructing a list of about 90 process parameters that impact energy use, cost, and productivity. Reviews at NUCOR eventually reduced the list to about 10 parameters, representing almost 80% of the process energy savings potential. Technology changes that would impact the parameters were examined and quantified in terms of effects on product cost, throughput, and energy use. NUCOR now is selecting technologies for further development or immediate implementation, depending on the status of each particular technology. The value chain analysis results gives NUCOR a sound basis for making and justifying those decisions.

As a next step, ORNL plans the same type of analysis in a vertically integrated mill. After that, a comparison of issues and opportunities at both vertically integrated steel mills and mini-mills will be done.

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High Carbon Fiber Content

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materials in an automotive environment. Predictive models are being created to account for the synergistic effects of environmental stressors. Designs are being developed that use the positive properties of composites to advantage while minimizing the effects of their drawbacks. The designs are being tested in production prototypes of automotive structures. Crash energy management models for automotive composites are being developed that will enable designers to minimize component weight without compromising safety.

Joining and inspection. We are exploring methods of joining composites to composites and to other materials. Current efforts concentrate on adhesive formulation, modeling, processing, and testing of adhesive bonds. The synergistic effects of environmental stressors on adhesive joint integrity are being characterized. Future efforts will concentrate on thermoplastic welding, thermoset reaction bonding, adhesive rapid cure technologies, bolting, and novel attachment technologies. We are developing methods of evaluating bond integrity that are robust enough for a manufacturing facility, fast enough for a production line, and reliable enough to ensure passenger safety. Laser shearography has proved to be one of the most successful techniques to date.

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I&C Laboratories Specialize

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phenomena. Particularly distinguished capabilities exist for development, fabrication, and testing of detectors for measuring ionizing and nonionizing radiation.

Controls and simulation have been developed and used in process control, manufacturing, and safety systems and in ultrareliable applications such as nuclear reactor control and protection systems. The modular approach taken by our engineers is applicable to most large, complex control systems and may be used for system development or personnel training.

For more information about ORNL's I&C laboratories, see www.ic.ornl.gov/.

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Bringing You Better Brakes

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materials and braking systems for the U.S. heavy trucking industry. The findings of the workshop will be included in the multiyear program plan of DOE's Office of Heavy Vehicle Technologies. During the coming year, ORNL will continue to expand its research in brake materials to address such friction-and-wear-critical issues as the replacement of cast iron rotors in cars and light trucks with lightweight metal matrix composites.

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News Briefs

Outstanding Young American

Patricia Garland, a member of ORNL's Buildings Technology Center staff, has been named one of 10 Outstanding Young Americans for 2000 by the Junior Chamber of Commerce. She is assigned to the ORNL Washington office as technical program manager for DOE's Thermally Activated Heat Pump Program. She also is the U.S. team leader for Annex 24, an international group that directs research to improve energy efficiency and reduce greenhouse gas emissions.

Garland, a chemical engineer, is the author of more than 20 technical publications in energy efficiency and chemical engineering, and she has made presentations in 14 states and four countries. She is the national secretary for the Society of Women Engineers.

Riding the White Lightning

A fleet of new green vehicles rolling around ORNL is powered by a mixture of 85% ethanol and 15% gasoline. They were purchased as a result of a presidential order to federal facilities to develop vehicle fleets that use non-fossil fuels. The initiative is part of a larger DOE-led effort to reduce U.S. dependence on imported oil. Most ethanol on the market today is produced from corn, which can be grown domestically. Alternative domestic feedstocks are being developed.

ORNL's EE/RE Transportation Technologies Program, the ORNL Plant and Equipment Division, and DOE-ORO Procurement worked together to obtain the vehicles, a steady supply of ethanol fuel, and a fueling station. A. E. Staley Company in Loudon, a major ethanol producer, mixes and delivers the high-proof fuel. (Gasoline is added so that the fuel will burn with a visible flame.) Ethanol fuel sold in retail filling stations usually mixes only about 10—20% ethanol with gasoline.

Michael Fielden (left), Kaye Johnson, and John Klemski fill up one of ORNL's new ethanol-burning cars.

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