Science and Technology for a Sustainable Energy Future

Accomplishments of the Energy Efficiency and Renewable Energy Program at
Oak Ridge National Laboratory

UTILITIES

TRANSPORTATION

INDUSTRIES

BUILDINGS

Prepared by the Oak Ridge National Laboratory for the Office of Energy Efficiency and Renewable Energy,
U.S. Department of Energy

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Science and Technology for a Sustainable Energy Future

Accomplishments of the Energy Efficiency and Renewable Energy Program at Oak Ridge National Laboratory

**Marilyn A. Brown
Kathi H. Vaughan**

March 1995

Prepared for the
Office of Energy Efficiency and Renewable Energy
U. S. Department of Energy

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
Managed by Martin Marietta Energy Systems, Inc.
for the U.S. Department of Energy
under Contract DE-AC05-84OR21400

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CONTENTS

SUMMARY	v
INTRODUCTION	1
The Changing Marketplace	1
Overview of the Program	4
Strong Partnerships with Industry and Universities	4
<i>Advisory Boards and Technical Review Committees • Program</i>	
<i>Sponsorship • Subcontracting • Cooperative R&D • User Facilities</i>	
<i>• Educational Programs</i>	
Unique Research Facilities	6
Indicators of Success	10
<i>Scientific Awards and Peer Recognition • Patents and Licensing •</i>	
<i>Commercialized Technologies • Satisfied Customers</i>	

Highlight: *What our Customers are Saying, 12*

BUILDING TECHNOLOGIES	15
Building Envelope Systems	15
Building Materials	16
Heating and Cooling Equipment	18
<i>Electric-Powered Heat Pumps • Thermally Activated Heat Pumps •</i>	
<i>Refrigeration Systems</i>	
Existing Buildings	28
Technology Transfer	30

Highlights: *From R-3 to R-30 in Thirty Years, 17 / ORNL Software Helps Industry Design Better Heat Pumps, 19 / Heating and Cooling with Low Electric Demand—The Generator-Absorber Heat Exchange, 22 / Next-Generation Gas Chillers on the Brink of Market Introduction, 24 / Improving Supermarket Refrigeration, 24 / CFC/HCFC Alternatives for the Buildings Sector, 26 / Measuring Particle Drift Velocity to Identify In Situ Refrigerant Mixtures, 27 / Rebuild America, 29 / The Interactive Zip Code Insulation Program (ZIP), 32 / Collaborating with a Historically Black University, 33*

TRANSPORTATION TECHNOLOGIES	35
Partnership for a New Generation of Vehicles	36
Transportation Materials	37
<i>Ceramic Technology • Lightweight Materials • Alternative Fuels</i>	
<i>Materials Issues • Tribology</i>	
Alternative Fuels	43
<i>Biofuels Feedstock Development • Poplar Breeding Success •</i>	
<i>Alternative Fuels Utilization • Bioreactors for Alcohol Fuel</i>	
<i>Production</i>	
Propulsion Systems	46
<i>Automotive Propulsion Technology • Environmental Control Technology</i>	
Transportation Data and Policy Analysis	46

Highlights: *Use of Sintered Silicon Carbide as a Seal Face in Automotive Water Pumps, 38 / Ceramic Cutting Tools Market Recaptured for American Industry by ORNL Technology, 39 / Super Grip for Tensile Testing of Ceramics, 40 / Chand Kare Technical Ceramics—A Minority-Owned Small Business, 40 / Coors Ceramics Company, 41 / Technology Transfer—With a Personal Touch, 42 / Cooling Cars for Less, 47 / Telecommuting—A New Way to Get to Work, 49*

INDUSTRIAL TECHNOLOGIES	51
Advanced Material and Manufacturing Technologies	51
<i>Advanced Industrial Materials • Continuous Fiber Ceramic Composites • Advanced Bioprocessing Concepts • Thermal Sciences Research • Alternative Feedstocks for Chemicals Production • Paper Pulping Processes</i>	
Waste Reduction Technologies	60
<i>Advanced Industrial Heat Exchangers • Industrial Heat Pumps • Advanced Turbine Systems • Energy-Efficient Motors and Drive Systems • Cellulosic Waste Minimization and Bioconversion</i>	

Highlights: *Nickel Aluminide Alloy Finds Commercial Applications in the Steel and Die-Making Industries, 52 / Advanced Ceramic Composite Material for Industrial Gas Turbine Combustor Liners—The GE Team's Approach, 54 / Materials Absorb "Magic Frequencies" in Revolutionary Microwave Furnace, 55 / Fluidized-Bed Bioreactor Economics Look Good, 56 / New Method for De-inking Waste Newspaper, 59 / The Motor Challenge, 61 / Get a "Lift" from Industrial Heat Pumps, 62*

UTILITY TECHNOLOGIES	63
Power Systems Technology	63
<i>High-Capacity Transmission Options • Electric and Magnetic Fields</i>	
Superconductivity Program for Electric Power	65
Hydrogen Production and Fuels Infrastructure	67
Renewable Energy Conversion	68
Environmental Impacts	69
Thermal Energy Storage	70
Electric Industry Policy Studies	70

Highlights: *Whose Commitments Will Be Stranded by Utility Reorganization? 72*

CROSS-CUTTING PROGRAMS	73
Support for National Programs	73
<i>National Weatherization Evaluation • National Energy Audit • Energy-Related Inventions Program</i>	
Support for IEA Programs	76
<i>Greenhouse Gas Technology Information Exchange • Center for the Analysis and Dissemination of Demonstrated Energy Technologies • IEA Heat Pump Program</i>	
Support for International Initiatives	79

Highlights: *Advanced Audit Now Used Nationwide to Select Retrofit Measures, 75 / Technology Adaptation and Market Conditioning in India, 81 / Innovative Uses of Biomass Energy in China, 82*

REFERENCES, CONTACTS, AND ACKNOWLEDGMENTS	83
--	-----------

SUMMARY

The Energy Efficiency and Renewable Energy (EE/RE) Program at Oak Ridge National Laboratory (ORNL) was established in 1978 to facilitate the Laboratory's research and development (R&D) on energy efficiency and renewable energy technologies. The mission of the program is to assist the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy in accelerating the development and deployment of sustainable energy technologies, thereby creating a cleaner environment, a stronger economy, and a more secure future.

The program employs an integrated approach to achieve this mission: it combines applied research with technology development and deployment activities; it draws on the expertise of multidisciplinary teams capable of tackling large and complex problems; and it involves a wide array of industrial, academic, and public-sector partners in the definition, execution, and assessment of its activities. Widespread utilization of its research results and swift transfer of its technologies into commercial applications are accomplished through user facilities, cost-shared subcontracts, cooperative R&D agreements, and licensing, as well as publishing, exhibits, and participation in conferences and symposia.

ORNL performs research and development on scientific problems and advanced technologies that touch all sectors of the economy: transportation, buildings, industry, and utilities. ORNL also conducts program evaluations, utility resource planning, policy analysis, and international deployment activities. The EE/RE Program has produced significant energy, environmental, and economic benefits for the nation. Overall, the program has

- attracted \$29.5 million in industry cost-sharing through cooperative R&D agreements and superconductivity collaborative agreements; and
- generated \$95 million in product sales through licensing of ORNL inventions.

In the buildings sector, the program has

- led to cumulative energy savings of \$8.4 billion to date, due to advances in heat pump and refrigeration technologies including
 - the displacement of air-source heat pumps by ground-coupled heat pumps, resulting in more than \$90 million of energy savings;
 - the accelerated market entry of high-efficiency single-speed heat pumps and central air conditioners by 5 years during the mid-1980s, resulting in cumulative savings over the 5-year period of about 0.05 quads, or over \$350 million in cost reductions;
 - improved compressors for refrigerators that resulted in at least 0.85 quads of energy savings, or \$6 billion in cost savings to the American public; and
 - a controls strategy for supermarket refrigeration that is responsible for about 0.3 quads of energy savings, or approximately \$2 billion in cost savings;

- accelerated the market introduction of vacuum insulation panels, which feature fine powders or other filler materials contained within an envelope composed of plastic film or thin metal sheet and offer five to ten times the R-values of standard fiberglass or foam insulations; and
- discovered that R-values of loose-fill fiberglass insulation in attics can decrease by as much as a factor of 2 in cold climates, resulting in more accurate labeling and performance standards and better test procedures.

As the result of transportation R&D, the program has

- helped reestablish U.S. leadership in the ceramic cutting tool market by contributing to the creation of cutting tools made from silicon carbide whisker-reinforced aluminum oxide;
- contributed to the creation of numerous other ceramic products, including
 - automotive water pump seals made from an improved silicon carbide ceramic called Hexoloy SA;
 - prototype engine components from silicon nitride;
 - ceramic-coated piston rings manufactured from a proprietary ceramic composition; and
 - in situ toughened silicon nitride components for auxiliary power units, rocket engine turbine pumps, and industrial gas turbines.
- invented an economic way of increasing the efficiency of automobile air conditioners by 20%;
- contributed to the creation of a new hybrid poplar with leaves that are 4 times larger than those of its parent plants and that is being grown commercially by three forest products companies in the Pacific Northwest; and
- conducted analyses and produced data on transportation energy use that has provided a strong foundation for designing and assessing government policies.

In the industrial sector, the program has

- invented a new class of high-temperature intermetallic alloys that are being introduced in the steel and die-making industries to improve energy efficiency, productivity, and product quality;
- developed and demonstrated an improved bioreactor for ethanol production with more than a ten-fold increase in volumetric productivity;

- invented and developed a variable-frequency microwave furnace with the potential for widespread industrial application that is now being manufactured by a company under a licensing agreement, representing a whole new line of business and expanded markets for that company; and
- invented an environmentally friendly, energy-saving technology for removing ink from waste newspapers to make recycled paper products.

In the utility sector, the program has

- begun monitoring the world's first commercially operated six-phase transmission line, which has the potential of increasing line capacity by 73 percent;
- invented superconducting aerosol powders that experienced their first commercial sale in 1994, under a licensing agreement;
- discovered a nuclear gene deletion mutant alga that performed photosynthesis with only Photosystem II, doubling the theoretical efficiency of hydrogen production;
- contributed to the expansion of utility investments in demand-side management (DSM) programs by developing standard methodologies for measuring the energy saved by programs; and
- developed and applied methods to help electric utilities assess a broad range of energy options to meet customer energy-service needs.

As the result of its cross-cutting R&D activities, the program has

- enabled energy cost savings in the homes retrofitted in 1995 by DOE's Weatherization Assistance Program to increase by \$56 million through the use of the DOE/ORNL National Energy Audit to select retrofit measures, with no increase in cost per home; and
- created a strong basis of field experience in developing countries and energy economics to support DOE's new initiatives in sustainable energy and trade.

Many other accomplishments and high-probability, near-term successes are documented in this report. Thus, the payback to the nation's R&D investments in ORNL's Energy Efficiency and Renewable Energy Program has already been substantial, and numerous developments are on the verge of offering further dividends.

INTRODUCTION

The Energy Efficiency and Renewable Energy (EE/RE) Program at Oak Ridge National Laboratory (ORNL) was established in 1978 to facilitate the Laboratory's research and development (R&D) on energy efficiency and renewable energy technologies. The mission of the program is to assist the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (DOE/EE) in accelerating the development and deployment of sustainable energy technologies, thereby creating a cleaner environment, a stronger economy, and a more secure future. The program employs an integrated approach to achieve this mission: it combines applied research with technology development and deployment activities; it draws on the expertise of multidisciplinary teams capable of tackling large and complex problems; and it involves a wide array of industrial, academic, and public-sector partners in the definition, execution, and assessment of its activities.

The program's mission reflects a national commitment to an expansion of our energy resource options and to greater efficiency in every element of energy production and use. More diverse resource options and greater energy efficiency will help to ensure a sustainable national energy system—one that meets the needs of the current population while preserving the means to meet the needs of future generations.

While the EE/RE Program's mission relates primarily to the enhancement of energy resources, the program also seeks to contribute significantly to DOE's other mission areas: science and technology, environmental quality, and national security.

- Science and technology is advanced as a result of the program's unique facilities and high-quality scientific and engineering staff.
- Environmental quality is enhanced by the development of energy-efficient and renewable options that reduce greenhouse gas emissions and prevent pollution.
- National security is promoted through the creation and expansion of energy options that decrease the nation's vulnerability to energy supply interruptions and price fluctuations.

In addition, improved industrial competitiveness is a strong derivative benefit of the program. Industrial competitiveness is promoted through improvements in the energy and materials efficiency of industry and commerce and through the creation of technologies that lead to new products, jobs, and export markets.

THE CHANGING MARKETPLACE

Since 1958, the United States has consumed more energy than it has produced, resulting in growing imports of energy, especially petroleum, and an unfavorable balance of payments. Although U.S. energy consumption decreased briefly in response to the crude oil price shocks of the 1970s, the relatively low oil prices of the late 1980s and 1990s have caused energy consumption to rise again, resulting in a 1993 national energy bill of nearly \$500 billion and a reliance on foreign sources for more than half of the oil we use. Oil imports are now at their all-time highest levels and comprise 40% of the nation's entire trade deficit.

The following figure shows the amounts and sources of energy produced and consumed in the United States in 1993, when energy demand reached a record level of 84 quads.¹ Domestic energy production totaled only 66 quads, resulting in a shortfall of 18 quads, or 21% of the nation's annual energy budget.

Each of the three major end-use sectors (residential and commercial buildings, industry, and transportation) has increased its energy use since 1949, when annual data were first made available from the Energy Information Administration.

- Energy consumption in the **residential and commercial** sector has increased at the greatest overall pace, nearly tripling since 1949 to an all-time high of 30 quads in 1993.

Total energy production and consumption in the United States in 1993 (in quads). Source: Energy Information Administration, U.S. Department of Energy, Annual Energy Review 1993. (DOE/EIA-0384) July, 1994, p. 3.

- Energy consumption by the **industrial** sector was most responsive to the turmoil in energy markets after the 1973–74 Arab oil embargo, when its consumption declined to a 16-year low of 26 quads in 1983. However, energy consumption in this sector more than doubled over the 45-year period, reaching a new maximum of 31 quads in 1993.
- Growth in energy consumption by the **transportation** sector is dominated by an expanding consumption of petroleum, which historically has been the fuel most vulnerable to price shocks. Although growth in energy use for transportation purposes was slower during the 1980s than in previous decades, this sector consumed a new high of 23 quads of energy in 1993.

The last decade of rising energy consumption in the United States comes at a time when concern over the environmental consequences of energy use has stimulated renewed interest in energy-efficient practices and a desire to expand the use of renewable resources such as solar, biomass, and

¹ A "quad" (1 quadrillion British thermal units, or Btu) is a standard unit used in comparing large amounts of energy derived from diverse sources, or used in differing applications—based on converting the respective total energy contents into heat equivalents. For example, 1 quad is roughly equal to the energy contained in the oil that would be used in 1 year if daily consumption were 500,000 barrels.

geothermal energy. The inconsistency between this growing environmental ethic and the rising consumption of fossil fuels is partly the result of marketplace failures that occur when private actions (such as the purchase of an energy-inefficient industrial boiler or a gas-guzzling automobile) have significant

social costs (e.g., excessive emissions of greenhouse gases and conventional pollution) that the purchaser does not pay for directly.

The goals of a healthy environment and reduced dependence on insecure energy supplies represent national security, foreign policy, and social benefits that are undervalued by markets. The marketplace also underinvests in long-term, broad, basic research and risky precompetitive technologies, which are the focus of ORNL's EE/RE Program. Hence the need for government involvement.

Energy consumption by end-use sector, 1949–1993 (in quads). Source: Energy Information Administration, U.S. Department of Energy, *Annual Energy Review 1993*, (DOE/EIA-0384) July, 1994, p. 3.

Working with industrial, academic, and public-sector partners across the country, ORNL has accelerated the development of energy-efficient and renewable energy options that are both good for business and good for the country. Reflecting the increasing energy consumption experienced by all three end-use sectors, the Laboratory's EE/RE Program, like that of its primary sponsor, the U.S. Department of Energy, conducts research and develops technologies to efficiently and cost-effectively meet the energy needs of households, commercial businesses, and industrial operations. It also conducts R&D to exploit the significant efficiency improvements possible in the generation, transmission, and distribution of electricity.

The accomplishments described in this report illustrate the significant energy, economic, and environmental benefits that government-sponsored energy R&D can produce. Without the scientific accomplishments and technologies that DOE's national laboratories have produced to date, the nation's energy bill would be much higher today. In 1970, the United States consumed 23,000 Btu of energy for each 1987 dollar of gross domestic product (GDP). By 1993, the energy intensity of the economy had dropped to 16,000 Btu per 1987 dollar of GDP, representing a 30% improvement and annual savings of more than \$100 billion in energy costs.

Many factors have contributed to the economy's improved energy efficiency, including a significant restructuring of energy-intensive manufacturing activities and the implementation of demand-side management (DSM) programs operated by the nation's electric and gas utilities. In addition, the

national laboratories that support DOE/EE have played a key catalytic role, and their ongoing R&D programs will lead to a more sustainable energy future, as this report documents.

OVERVIEW OF THE PROGRAM

The EE/RE Program at ORNL is divided into the following five major research areas:

- technologies for efficient buildings, including heat pumps, appliances, roofs, walls, foundations, insulating materials, and retrofit of existing structures;
- technologies for transportation systems, including advanced automotive technologies, advanced materials, utility of alternative fuels (including biofuels), and transportation data and policy analysis;
- technologies for industrial processes, such as bioprocessing, electric motor systems, waste heat utilization, and advanced materials;
- technologies for electric utilities, including high-temperature superconductors, transmission and distribution systems, and integrated resource planning; and
- evaluation of energy efficiency and renewable energy programs, policy analysis, and assistance with domestic and international deployment activities.

The program combines applied scientific investigations with technology development and deployment activities. It also capitalizes on the basic research ongoing at ORNL and elsewhere to enrich its programs. Research has shown that successful development and deployment of market-ready technologies requires strong efforts during every stage of the product development cycle. By remaining involved with stakeholders from the time that R&D problems are defined until the solution is implemented, ORNL is able to increase the probability of successful deployment.

Another hallmark of the EE/RE Program is the use of interdisciplinary teams with the skills to tackle problems of great complexity and scope. This integrated approach is further extended by the use of collaborative efforts with industry, academia, and other government agencies. This partnership approach is described below.

STRONG PARTNERSHIPS WITH INDUSTRY AND UNIVERSITIES

Collaboration and partnerships with industry, academia, and government agencies around the country have become the established mode of operation for the Program. Through these partnerships, the expertise and resources of ORNL are teamed with those of other complementary institutions in a way that often shortens the time between basic scientific discoveries and product developments. Strong partnerships are used extensively by ORNL to increase the effectiveness of its EE/RE Program.

Advisory Boards and Technical Review Committees. Systematic planning and program reviews conducted in coordination with advisory boards and technical review committees serve as essential inputs for program development and resource allocation decisions. The involvement of

stakeholders on these committees helps ORNL gain a better understanding of customer requirements, leverage knowledge, and financial resources, and communicate their results to potential users by learning what channels and formats stakeholders find useful and credible.

Program Sponsorship. The primary sponsor of the EE/RE Program is the U.S. Department of Energy. However, numerous other government agencies, private companies, and nonprofit organizations have sought ORNL's services to conduct research and develop technical solutions to meet their needs. The high volume of work for sponsors other than DOE attests to the fact that ORNL's program is meeting the needs of many stakeholders.

Subcontracting. Forty percent of the EE/RE Program's budget is directed to subcontractors, who work under the technical supervision of ORNL scientists. In several instances, these subcontractors have been small businesses that have developed and received patents for technologies resulting from their research for ORNL.

Cooperative R&D. The EE/RE Program makes extensive use of cooperative research and development agreements (CRADAs). These agreements involve a working partnership in which ORNL and at least one private company or trade association agree to pool their resources toward the solution of a problem of interest to both parties. In 1990, when the CRADA was authorized by Congress as a means of working with industry, ORNL was the first DOE national laboratory to enter into a CRADA. Since then, the ORNL EE/RE Program has participated in 46 CRADAs with a value of \$28,634,000. Approximately half of that amount (or \$14 million) represents cost sharing by industrial partners.

ORNL helped to develop the CRADA mechanism by creating a precursor R&D agreement that enabled industrial collaboration in the Superconductivity Partnerships Program. To date, 33 superconductivity collaborative agreements have been signed, resulting in more than \$15.5 million in program cost sharing from industry. In total, ORNL's EE/RE Program has attracted \$29.5 million in industrial cost sharing through CRADAs and superconductivity collaborative agreements, thereby significantly enhancing the resources available to achieve the program's (and DOE's) mission.

User Facilities. The EE/RE Program has three user facilities that are designed to serve not only ORNL staff scientists and engineers, but also researchers from industries, universities, and laboratories. They simultaneously advance national research and development and fulfill DOE missions by minimizing unnecessary duplication of effort, promoting beneficial scientific interactions, and making the most effective use of costly and, in many cases, unique equipment. The three user facilities are

- the High Temperature Materials Laboratory (HTML);
- the Buildings Technology Center (BTC); and
- the Bioprocessing Research User Facility (BRUF).

Educational Programs. Partnerships with universities have brought numerous undergraduates, graduate students, and faculty members to work at the laboratory, sometimes for extended periods. In addition, ORNL scientists have worked with several historically black colleges and universities to enhance their R&D capabilities and to help underrepresented minority students pursue degrees in science and technology. For instance, ORNL's Ceramic Technology Program has collaborated with North Carolina A&T State University since 1984, providing nearly \$2 million for research and equip-

ment purchases and to train graduate students in mechanical engineering. The strong collaboration with Tennessee State University is profiled in the chapter on building technologies.

Another noteworthy example is the HTML Fellowship Program, which has multiple educational goals. It encourages U.S. citizens to pursue graduate training in ceramic education, it provides opportunities for U.S. faculty and postdoctoral appointees to pursue research at HTML, and it assists industrial researchers in conducting research projects of interest to their employers. Currently, the program hosts six graduate students, one faculty fellow, and three industrial fellows.

UNIQUE RESEARCH FACILITIES

Three user facilities are supported by the EE/RE Program at ORNL. Each of these is available to outside researchers.

The **High Temperature Materials Laboratory (HTML)** is a modern research facility designed to help solve the high-temperature materials problems that have limited the efficiency and reliability of advanced energy-conversion systems. The laboratory serves as a focal point for multidisciplinary research on new ceramics and metallic alloys that have potential for high-temperature applications. It is a major user facility that provides members of the industrial and university research communities access to an extensive array of special research equipment needed to characterize the microstructure and microchemistry of materials and to investigate the effects of these parameters on the physical and mechanical properties of the materials. A primary objective of the HTML is to facilitate materials R&D in order to assist U.S. industry in meeting the current challenge of foreign competition in the area of high-temperature materials.

The HTML contains six "user centers," each of which is devoted to a specific area of research in materials science. These research areas are as follows:

- materials analysis—used to determine surface chemistry and microstructure down to the atomic level;
- X-ray diffraction—used for studies of materials at temperatures up to 2,700°C in a vacuum and to 1,500°C in air;
- physical properties—used to study thermal stability, expansion, and conductivity;
- mechanical properties—used to measure fracture toughness and tensile strength;
- machining and inspection research—used to perform materials finishing research and to conduct highly accurate dimensional measurements; and
- residual stress—used for measurements of residual stress and texture of ceramics and alloys.

A member of the research staff is available in each of the centers to work with users and to assist them in planning, performing, and conducting experimental research; to help them interpret research results; and to maintain safe environmental conditions and efficient instruments.

Vyckoslav Frahetsvic and Raja Mishra, G.E. North American Research and Development Center, analyze a specimen with the 400-keV JEOL transmission electron microscope in the HTML.

Sophisticated research instruments are available for characterizing the makeup and properties of materials over a wide range of temperatures. This state-of-the-art instrumentation includes scanning- and transmission-electron microscopes, scanning microprobes, and other spectroscopic devices that allow the surface and grain boundary structures and compositions of crystalline materials to be characterized precisely. The information thus produced can then be related to the physical and mechanical properties, measured as a function of temperature, that are extremely important to ultimate applications. With these tools, scientists are able to analyze ceramic materials atom by atom. These tools assist industrial and university users in developing improved materials and in solving economically important materials problems. The HTML is also home to the HTML Fellowship Program, described earlier.

The **Buildings Technology Center (BTC)** provides the U.S. buildings industry with broad access to a unique collection of testing and analysis capabilities. The Center focuses on improvements in the energy efficiency of buildings. The mission of the BTC is to use diverse and unique staff capabilities and research facilities to help DOE, U.S. industry, and other customers identify issues and solve problems of major significance to building systems, environmental control, and energy delivery. It pursues solutions that are energy-efficient, environmentally sound, and cost-effective. It stimulates, leads, and participates in partnerships for technology development and implementation.

The BTC is housed in a cluster of six buildings with over 20,000 square feet of space and has a permanent staff of about 50, which is continuously supplemented by 10 to 20 guest workers. The facility is composed of three centers of expertise: Building Envelope Research, Heating and Cooling Technology, and Existing Buildings Research.

Factors that affect roof performance—temperature, humidity, and exposure to the sun—can all be simulated in the Large Scale Climate Simulator at the Buildings Technology Center. A full-scale roof system is placed inside the simulator here.

The centerpiece test facility for Building Envelope Research is the large-scale climate simulator, where large roof sections are sandwiched between two environmental chambers. The upper climate chamber simulates any outdoor weather condition on earth; the lower metering chamber models interior conditions. The BTC also has a number of other capabilities:

- the rotatable guarded hot box to test full-size wall, fenestration, roof, and floor systems;
- the roof thermal research apparatus, with eight replaceable roof panels, four replaceable wall panels, and a controlled interior;
- two calibrated slab-foundation edges to measure thermal performance of slab-on-grade;
- the envelope systems research apparatus, which is used to study energy and moisture flow through building envelopes;
- a large, two-room (indoor/outdoor) environmental chamber used to simulate temperatures and humidity conditions for the development of air-conditioning, refrigeration, and heat pump technology;
- calorimeters and specialized test apparatus for evaluating chlorofluorocarbon and hydrochlorofluorocarbon replacement refrigerants; and

- a wide array of sensors and data acquisition systems to analyze building performance in the laboratory and in the field.

The **Bioprocessing Research User Facility (BRUF)** houses laboratories for the investigation of advanced bioprocessing concepts using stirred-tank and columnar bioreactors and a fermentation pilot plant for large-scale batch and columnar experiments. Other research and support laboratories are available on-site.

R&D activities include (but are not limited to) feedstock pretreatment and fractionation, microbial culture selection and improvement, genetic manipulation, microbial and enzyme immobilization, advanced bioreactor concepts, biotreatment of wastes, process feasibility and scale-up, advanced and analytical concepts, bioprocess monitoring and control, and biochemical separations. Recent users have included a small industry that is using the large fermentor to produce test batches of biomass-derived products and optimize their procedures. Microbes have been produced for subsequent biosorption of heavy metals, for production of cellulase, and for extraction of key enzymes. Academic researchers have produced immobilized biocatalysts for hydrodynamic studies of fluidized beds and for tests of new ethanol bioreactors.

The BRUF provides outside industrial and academic users with state-of-the-art equipment. The stirred-tank and advanced columnar bioreactors that are available range in size from bench scale to greater than 500 liters. Several instrumented stirred-tank fermentors, ranging from 50 to 500 liters, can be used for large-scale demonstrations, process scale-up studies, or production of kilogram quantities of microorganisms or biochemicals under controlled conditions. The columnar bioreactors range from 2.5 to 40.6 centimeters in diameter and vary in height from approximately 30

Researcher at the Bioprocessing Research User Facility

centimeters to 60 meters. They can be operated as fixed beds or fluidized-bed bioreactors and are equipped to accommodate a variety of process monitoring and control equipment. Apparatus exists for the production of uniform, immobilized biocatalysts. Large equipment available for product separation and recovery includes continuous centrifuges, homogenizers, and a cross-flow filtration unit.

Users of the facility have access to a variety of analytical equipment, such as gas chromatographs, spectrophotometers, carbon and nitrogen analyzers, high-pressure liquid chromatographs, and ion chromatographs. A cold room, environmentally controlled growth chambers, anaerobic hoods, autoclaves, sterile culture-transfer areas, refrigerators and freezers, freeze-dryers, microscopes, a hammer mill, and other laboratory equipment as well as computer facilities are available.

The BRUF includes laboratories equipped for mammalian tissue culture and molecular genetics studies and a large facility for animal handling. Containment facilities for recombinant DNA studies can be used for the development of advanced analytical techniques and for conceptual investigations of advanced bioreactors. Among the BRUF's supporting facilities are machine, instrument, and glass shops; several electron microscopes; library and information services; computer graphics, a variety of state-of-the art analytical chemistry services; and other user facilities.

INDICATORS OF SUCCESS

The success of ORNL's EE/RE Program can be measured by many different performance metrics, including the numbers and types of scientific awards and peer recognition; licenses and commercialized technologies; and satisfied customers. In each of these areas, the success of the program has been strongly validated. The performance of the program along these dimensions is summarized below.

Scientific Awards and Peer Recognition. ORNL has received several "R&D 100" awards for the scientific achievements of its EE/RE Program. These awards are given annually to technology innovations (in both the public and private sectors) that have strong prospects for commercial success. Program staff members have also received awards from the Federal Laboratory Consortium, the Technology Transfer Society, *Popular Science*, *Progressive Architecture* magazine, ASHRAE, and the National Research Council's Transportation Research Board.

ORNL researchers in the EE/RE Program have a strong international record of publishing in leading peer-reviewed journals. Their technical leadership is also illustrated by the numerous major workshops and conferences that have been initiated, organized, and run by ORNL scientists. For instance, ORNL started the Symposium on Biotechnology for Fuels and Chemicals, which is now chaired jointly with the National Renewable Energy Laboratory and will hold its 17th annual meeting in 1995. Similarly, ORNL will chair the Performance of the Exterior Envelopes of Buildings Thermal VI Conference in 1995, an annual international meeting which it initiated in 1990, that provides a forum for sharing R&D results on energy-efficient building technologies.

Patents and Licensing. Researchers have patented numerous efficiency and renewable energy technologies as the result of research conducted by ORNL staff members or by industrial and university partners participating in DOE/ORNL programs. Many of the patents held by other organizations as the result of DOE/ORNL-sponsored research have led to successful commercial products, as the following chapters document. In addition, 32 licensing agreements have been signed to commercialize the patented efficiency and renewable energy inventions of ORNL researchers. These agreements have generated \$1.7 million in royalties based on \$95 million in sales of the licensed technologies.

Many of the licensing agreements deal with advanced materials developed for high-temperature applications, in particular, silicon carbide whisker-reinforced ceramics and nickel aluminide alloys. However, a wide range of other technologies have been licensed, including the triple-effect absorption chiller, the variable-frequency microwave furnace, and an anaerobic digestion process for treating sewage. Many of these commercial developments, and their energy, environmental, and economic impacts, are described in the following chapters.

Commercialized Technologies. The following chapters document the numerous products, processes, and technologies that have been introduced into the market faster and with more cost-competitive, energy-saving features than would have occurred without the activities of the EE/RE Program.

Satisfied Customers. The following chapters provide comments from numerous satisfied customers, attesting to the program's long-standing history of meeting customer needs. In addition, the two-page highlight at the end of this chapter describes "What Our Customers are Saying" about different aspects of ORNL's EE/RE Program. The approximately \$30 million in cost sharing contributed by industry to ORNL projects through CRADAs and other collaborative agreements is a more quantitative indicator of customer satisfaction.

Licensing Agreements		
Technology	Company	Date Signed
Nickel Aluminide Alloys	Cummins Engine Co.	9/5/85
	Hoskins Manufacturing Co. (Armada Corp.)	6/23/87
	Hoskins Manufacturing Co.	3/25/91
	Metallamics, Inc.	12/1/87
	Armco Inc.	12/10/87
	Valley-Todeco, The Lamson & Sessions Co.	1/1/88
	Harrison Alloys, Inc.	11/16/90
	Special Metals Corp.	no date
Silicon Carbide Whisker-Reinforced Ceramics	Advanced Composite Materials Corp.	7/1/86
	Advanced Composite Materials Corp.	7/1/86
	High Velocity Tool Co.	10/1/86
	Iscar Ceramic, Inc.	1/12/87
	American Matrix, Inc.	1/31/87
	Dow Chemical Co.	3/26/87
	Cercom, Inc.	11/25/87
	Hertel Cutting Technologies	6/8/88
	GTE Valenite Corp.	9/28/88
	Kennametal, Inc.	7/1/89
	Keramont Corp.	7/16/90
	Advanced Innovative	2/14/92
Iron Aluminide	Amatec	11/19/90
	Cast Masters, Inc.	10/5/92
	Harrison Alloys, Inc.	11/16/90
Ductile Aluminide Alloys	Rapid Technologies, Inc.	12/21/93
Triple-Effect Absorption Chiller	Trane Co., Div. of Am. Standard, Inc.	11/8/88
	Apache Corp.	10/30/89
Sewage Treatment	Anflow, Inc.	2/5/86
Ceramic Gripper Assembly for Tensile Testing	Instron Corp.	9/1/86
Variable-Frequency Microwave Furnace	Microwave Laboratories, Inc.	12/9/91
Measurement of Vacuum in Sealed Thin-Wall Packets	VacuPanel, Inc.	7/31/92
Lead-Stabilized Superconductor	Superconductive Components, Inc.	4/4/93
Gelcasting	Coors Porcelain Co.	8/18/89

Licensing agreements for ORNL energy efficiency and renewable energy technologies.

Selected Industry Partners

Air-Conditioning and Refrigeration Institute
 Aladdin Industries, Inc.
 AlliedSignal, Inc.
 American Gas Cooling Center
 American Society of Heating, Refrigeration, and
 Air-Conditioning Engineers
 American Society for Testing and Materials
 American Superconductor Corp.
 Americold Compressors
 Armco, Inc.
 Association of Home Appliance Manufacturers
 Boise Cascade
 Carrier/United Technologies
 Cellulose Industry Standards
 Clayton Homes, Inc.
 Consolidated Edison
 Coors Porcelain Co.
 Coors Structural Ceramics Co.
 Cummins Engine Co.
 Dow Chemical Co.
 Dow Corning Co.
 Duke Power Co.
 Edison Electric Institute
 E.I. du Pont de Nemours & Co.
 Electric Power Research Institute
 Gas Research Institute
 General Electric
 General Motors
 IBM Corp.
 Intermagnetics General Corp.
 Koppers, Inc.
 Manville Sales Corp.
 Materials and Electrochemical Research
 Metallamics
 National Association of Home Builders
 National Fuel Gas Distribution Co.
 National Roofing Contractors Association
 North Carolina Power and Light
 Norton Co.
 Phase Change Technologies
 Polyisocyanurate Insulation Manufacturers Assn.
 PPG Industries, Inc.
 Rolls Royce
 SPI
 Synertech Systems Corp.
 Trane Co.
 US CAR
 Westinghouse Electric Co.
 York International

WHAT OUR CUSTOMERS ARE SAYING

"The members of the ARI Energy Conservation Subcommittee have asked me to write to you about . . . the Energy Division staff at Oak Ridge National Laboratory. . . . The work on heat transfer of R-22 substitute refrigerants will allow us to better design heat exchangers of the future. The periodical analysis of "not-in-kind" technologies keeps the industry apprised of technology barriers and breakthroughs. The Oak Ridge approach of conducting pre-competitive research, the results of which industry can tailor to its needs, is an example of an excellent government/industry partnership."

Mark Menzer, Vice President
 Research & Technology
 Air-Conditioning & Refrigeration Institute

"The HTML [*High Temperature Materials Laboratory*] has provided the opportunity to perform research necessary for design of NASP and ATF Engine Control Components. Without this facility, this high quality research would not have been practical. . . . Technically, the staff and center are first rate."

Rick Rateich
 AlliedSignal Aerospace

"We (GE-CRD) have found ORNL's help with our HTS wire development program to be invaluable. . . . Because of ORNL, we have learned vital information about why our samples work well that we wouldn't have learned without them. They have provided equipment, people, and expertise that we simply don't have. They have interacted with us very effectively and smoothly in producing these important results."

Dr. James W. Bray
 General Electric Corporate R&D Center

"The ORNL Building Equipment Research Program has served a fundamental role through conducting and sponsoring heat pump research and acting as a clearinghouse for heat pump technology information. . . . ORNL has built a reputation of technical strength and cooperation with industry in moving heat pump technology forward to the betterment of the U.S. as a whole.

"ORNL is the recognized U.S. center of expertise for air conditioner and heat pump analytical performance models which are publicly available and usable. Had these models not been available as a foundation for manufacturers' performing rating models, it is difficult to see how the industry could have responded to the mandated DOE rating procedures without severe contraction of the product choices available to the consuming public."

L. E. Chaump, Vice President, Engineering
 Trane Central Air Conditioning, Inc.

Selected Public Sector and Nonprofit Partners

Agency for International Development
 Alliance to Save Energy
 American Council for an Energy-Efficient Economy
 Army Materials Laboratory
 Bonneville Power Administration
 California Public Utilities Commission
 Council of American Building Officials
 Empire State Electric Energy Research Corporation
 Federal Highway Administration
 International Energy Agency
 Land and Water Fund
 Lawrence Berkeley Laboratory
 National Association of Regulatory Utility Commissioners
 National Association of State Community Services Programs
 North Carolina Department of Commerce
 National Community Action Foundation
 National Institute of Environmental Health Sciences
 National Institute of Standards and Technology
 National Renewable Energy Laboratory
 Natural Resources Defense Council
 New York State Electric & Gas Corporation
 New York State Energy R&D Authority
 New York State Public Service Commission
 Northwest Power Planning Council
 Pacific Northwest Laboratories
 Pew Charitable Trust
 Tennessee Valley Authority
 The Energy Foundation
 U.S. Department of Agriculture
 U.S. Department of Defense
 U.S. Department of Energy
 U.S. Department of Health and Human Services
 U.S. Department of Housing and Urban Development
 U.S. Department of Transportation
 U.S. Environmental Protection Agency

"Progress through partnership is a fresh, new and very welcomed way of coordinating and focusing our national efforts to achieve the technological breakthroughs that can make regulatory interventions irrelevant and make our industry more competitive internationally."

John F. Smith, Jr., President and CEO
 General Motors Corporation

"[I would like to thank DOE for] authorizing Eric Hirst, from the Oak Ridge National Laboratory, to visit our offices to conduct a roundtable discussion of his "statistical recoupling" proposal. The exchange was extremely informative and helpful to our work. . . . Over the years, the New York State Public Service Commission has benefited from help provided by the Oak Ridge, Lawrence Berkeley, and National Renewable Energy Laboratories."

Peter Bradford, Chairman
 New York State Public Service Commission

"The National Evaluation has produced the first comprehensive analysis of the amount of energy saved by DOE's low-income Weatherization Program. ORNL's work has laid the foundation for making the Program even more cost-effective by identifying opportunities for improvement and by describing innovative local agency approaches that can be emulated by others."

Dr. Laurence Kinney, President
 Synertech Systems Corporation

"ORNL has produced numerous papers in recent years on such matters as improving utility planning and policy, developing methods to increase DSM program impacts and improve program evaluation, and assessing approaches for more effective regulatory policies, such as addressing the regulatory and financial disincentives to utility investment in energy efficiency. . . . Because these studies have a national focus, they are an effective means for individual states to identify successful regulatory policies. From my experience, ORNL's research is objective, covers issues that state regulatory bodies do not have the resources to address, and contribute to more efficient and cost effective policy formulation at the state level."

Don Schultz, Demand-Side Planner
 California Public Utilities Commission

"There are numerous small businesses such as ours that have benefited or were started because the technologies we are involved in were developed through the support of the DOE's research programs."

Santosh Limaye, President and CEO
 LoTEC, Inc.

BUILDING TECHNOLOGIES

Over the past two decades, buildings have accounted for an increasing proportion of national energy consumption, rising from 33% in 1979 to 36% in 1993, and resulting in an annual energy bill of more than \$200 billion. The largest share of this energy is used to heat, cool, and ventilate building interiors, with lighting, water heating, and refrigeration as the next largest end uses of energy. Over the same two decades, improvements in the energy efficiency of building technologies have enabled less energy to be consumed per square foot of building space, but numerous cost-effective energy technologies remain underutilized.

The federal government has an especially important role to play in supporting R&D for the buildings sector, given the fragmented nature of the buildings industry historically and the limited R&D it supports. DOE's Office of Building Technologies (DOE/OBT) has supported the development of numerous high-efficiency building technologies. ORNL is responsible for field management in four program areas: Building Thermal Envelope Systems and Materials, Building Equipment Technology, Existing Buildings Research, and Buildings Technology Transfer. In each of these areas, energy-saving objectives are coupled with the goals of affordability, comfort, productivity, and safety in the built environment.

BUILDING ENVELOPE SYSTEMS

The energy performance of a building largely depends on the thermal properties of the materials from which it is built. By impeding the flow of heat, thermal insulation protects the conditioned interior space of a building from the exterior environment. Appliances such as refrigerators and ovens also use thermal insulation to improve their energy efficiency. The thermal resistance (R) per unit thickness of a material determines its ability to insulate. Batts, blankets, loose fill, or blown-in insulation have R-values in the range of 3 or 4 per inch. Plastic foams have about twice the R per inch but are presently produced using blowing agents that contain chlorine hydrochlorofluorocarbons, or HCFCs.

One of the early accomplishments of ORNL's building envelope systems research resulted from tests of loose-fill fiberglass attic insulation under cold climate conditions. The Building Technology Center's large-scale climate simulator allowed researchers to test the thermal resistance of attic test modules insulated with loose-fill fiberglass and subjected to varying temperatures both above and below the ceiling. The attic test modules demonstrated that the R-value of some loose-fill fiberglass insulations can decrease by as much as a factor of 2 in cold climates because of air circulation between the warm ceiling below the insulation and the cold attic space above. Previous laboratory tests across the country had missed the convection losses because the tests could not recreate attic conditions accurately. In 1992, this research project was selected as one of the year's 100 greatest achievements in science and technology by *Popular Science* magazine.

The findings of this research have already changed insulation performance standards in Minnesota, which now requires insulation R-values to be reported at winter design temperatures as well as at the mean temperature of 23.9°C (75°F), as mandated by the Federal Trade Commission. In addition, the American Society for Testing and Materials (ASTM) Committee on Thermal Insulation is developing new test procedures for attic insulation that capture insulation performance under realistic conditions in the field. These tests are likely to result in new national standards requiring manufacturers to reduce stated R-values to reflect insulation performance in actual winter conditions. The same project

Thermal performance of fiberglass loose-fill compared with batts at various heating season temperature differences across the attic insulation.

subsequently confirmed the efficacy of various covering systems, some of which contained polyethylene films, for stopping convection heat loss through insulation.

Analysis, modelling, and measurements at ORNL are leading to longer-lasting and more energy-efficient roofs. The major goal of this research is to develop as a marketable industry standard by the year 2000, a low-sloped roof that has an average service life of 30 years and an energy efficiency greater than an R-30 roof in a northern climate. Today's average roof has a life of 15 years and an installed R-value of 10. Dryable roofs are being developed cooperatively by ORNL and private industry. These roofs will not only last longer than conventional low-sloped roofs (potentially saving \$12 billion per year) but also will result in landfill space savings (0.4 billion cubic feet per year) and significant reductions in peak electrical generation requirements (potentially 900 megawatts in the southeastern United States alone). In addition, a joint project has been initiated with Dow Corning to examine the efficiency of reroofing with spray-foam insulation over an old, wet asphalt roof.

ORNL has also examined the thermal performance of alternative foundation and wall insulation systems. The resulting specifications for foundation insulation have been incorporated into the American Society of Heating, Refrigerating, and Air-Conditioning Engineers prescriptive standards (ASHRAE 90) and the Council of American Building Officials Model Energy Code, leading to energy savings of 0.38 to 0.45 quads per year by the year 2010. Several patentable energy-efficient wall systems with integral insulating capabilities have been developed at ORNL. These systems are acceptable to the pest control industry because they place insulation so that it is not in contact with the ground on either interior or exterior surfaces.

BUILDING MATERIALS

The building materials program addresses the development and characterization of new and existing insulation materials for buildings and refrigeration equipment. The goal is to develop new, cost-competitive materials that can reduce building energy consumption by 20% by 2010. Specific tasks are conducted in the areas of advanced materials research, existing materials performance, and

FROM R-3 TO R-30 IN THIRTY YEARS

ORNL has accelerated the market introduction of vacuum insulation panels, which feature fine powders or other filler materials contained within an envelope composed of plastic film or thin metal sheet. These panels offer five to ten times the R-values of standard fiberglass or foam insulations. Five CRADAs currently exist (with PPG Industries, the Appliance Research Consortium of the Association of Home Appliance Manufacturers, Dupont and VacuPanel, Aladdin Industries, and Clayton Homes and Tennessee Technological University) to develop powder-evacuated panels for refrigerator and building envelope applications. Future applications to domestic hot water heaters and other home appliances are anticipated.

Vacuum insulation panel vs. fiberglass batt

Time-line of R-values

retrofit insulation. Special emphasis is placed on development of powder-filled evacuated panels with an R-value greater than 50 per inch and a lifetime greater than 30 years (see highlight above, "From R-3 to R-30 in Thirty Years").

Domestic refrigerators and freezers, which have had to meet federal energy standards since 1994, currently use foam insulation blown with gases that contain chlorine. DOE-developed alternatives based on vacuum insulation concepts are nearing commercialization, and one of these, powder-filled evacuated panels, was introduced in refrigerators in 1993. This insulation material consists of a powder filler inside a porous bag with an outer barrier envelope evacuated to about 0.1% of atmo-

spheric pressure. The filler is a slightly compacted, small-diameter powder with 90% void space. These panels show R-values of 25 per inch and have been used to insulate steam pipes and high-temperature batteries. Other types of vacuum insulation panels are being developed for additional building applications.

HEATING AND COOLING EQUIPMENT

Competition is intense in the global marketplace for space-conditioning equipment. To restore U.S. technical leadership, the building equipment technology program generates new concepts and develops new technologies for improving the energy efficiency and load characteristics of energy conversion equipment for both residential and commercial buildings. The program includes research on electric-powered heat pumps, thermally activated heat pumps, refrigeration systems, and thermal and environmental control systems.

Electric-Powered Heat Pumps. The heat pump combines the functions of a standard air conditioner and furnace into a single high-efficiency compact unit, delivering more energy into the conditioned space than it extracts from the power line. In this way, compared to conventional electric resistance heating, the heat pump reduces the cost of energy to the nation and results in less pollution and global warming.

More than 50 companies in the United States manufacture electric-powered heat pumps and air-conditioning equipment. In 1992, purchases of heat pumps and air conditioners totaled 4.6 million units, representing approximately 20% of the total volume for the heating, ventilating, and air conditioning (HVAC) industry. Because of their widespread use, heat pumps are a major contributor to the U.S. economy. In 1992 the total value of shipments of heat pumps and air conditioners reached approximately \$3.7 billion. Their overall impact on the 1992 U.S. economy was estimated at \$27.3 billion. As this market continues to grow, the need for highly efficient, well-designed equipment will increase.

ORNL conducts analyses and experimental investigations in support of the DOE/OBT goal to develop and demonstrate a new generation of ozone-safe heat pump/central air conditioner technology that exceeds current state-of-the-art efficiencies by 25% or more (i.e., a seasonal energy efficiency ratio, or SEER, of 20 or higher). The centerpiece of this effort is a planned cost sharing effort with one or more manufacturers to build and demonstrate a preproduction prototype air-source system that achieves the efficiency goals by the year 2000.

ORNL has already contributed significantly to the improved efficiency of electric-powered heat pumps. Some of this progress has been fostered by the development of a variety of software tools that promote the design and use of energy-efficient building equipment. One of these tools is the DOE/ORNL Heat Pump Design Model, which is used by industry to design advanced heat pumps and air conditioners (see highlight). In addition, simpler versions of the DOE/ORNL Heat Pump Design Model have been developed to enable the rapid screening of a wide range of refrigerant and refrigeration circuit options. After narrowing the list of options, the Heat Pump Model can be used for detailed hardware design with the 'best' two to three options. This is the basis for the analysis approach being used for the advanced heat pump/central air conditioner technology development noted above. The simplified models have also been distributed to industry users.

In the early 1980s, ORNL conducted a pioneering study utilizing the Heat Pump Design Model that revealed that the efficiency of single-speed electric air-source heat pumps could be increased by more than 50% over then-current levels through the use of design optimization and higher-efficiency components (compressors, fans, heat exchangers, etc.). It is estimated that this early work accelerated the market entry of high-efficiency single-speed heat pumps and central air conditioners by 5 years during the mid-eighties. Cumulative savings over the 5-year period of market acceleration are esti-

ORNL SOFTWARE HELPS INDUSTRY DESIGN BETTER HEAT PUMPS

In the late 1970s, ORNL began work on developing computerized methods to aid in the design of new high-efficiency heat pumps and air conditioners. This DOE-sponsored effort has succeeded in developing the DOE/ORNL Heat Pump Design Model, which is widely distributed throughout the U.S. heat pump and air-conditioning industry.

This "public domain" software tool has been instrumental in industry development of the current generation of high-efficiency U.S. heat pump and air-conditioner products and has resulted in improved energy efficiency for the nation and enhanced competitiveness for the U.S. industry. Manufacturers using the model in their product development represent more than one-third of this market.

- Inter-City Products, the second largest heat pump manufacturer in the country, uses the model as its primary engineering design aid.
- The Trane Company coupled the model to an expert system to cut design time by 75% while improving design quality.
- Nordyne, a major heat pump manufacturer, used the model for product development and to create performance ratings of their equipment, including the Powermiser™ integrated water heating system.
- Lawrence Berkeley Laboratory applied

the tool in engineering analysis for new minimum efficiency standards.

- AlliedSignal employed the tool in the evaluation and design of refrigerant alternatives and has been instrumental in adding ozone-safe refrigerants to the program.
- The Gas Research Institute adapted the model for design analysis of engine-driven systems.
- The Electric Power Research Institute used the program to assess variable-speed commercial heat pumps.

Work is under way on the model to help meet the new challenges of phasing out chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants, as required to reduce adverse global climate impacts. These improvements will help manufacturers make the transition to environmentally safe refrigerants while maximizing equipment performance. Under a CRADA with DuPont, ORNL is developing a new version of the model for use in system design with these next-generation ozone-safe blends. To keep the model current to meet industry needs and desires, a more flexible and user-friendly modular version is planned for development. The "front-end" interface will be based on the absorption simulation model developed by the thermally activated heat pump program.

mated to be over \$350 million, or about 0.05 quads. This estimate is based on the following assumptions:

- an average central air conditioner and heat pump efficiency improvement of 30% over standard models;
- an average total annual sales of 2 million central air conditioners and 600,000 heat pumps (1981–1985);
- advanced units accounting for 10% of sales; and
- average annual heating and cooling loads of 8,000 and 4,000 kilowatt-hours, respectively.

Subsequent ORNL research activities through the 1980s focused on efforts to improve heat pump and central-air-conditioner efficiencies by reduction of dynamic losses (cycling, frosting, and defrosting), primarily through the application of capacity modulation techniques. ORNL analyses and experimental results showed that capacity-modulated heat pumps could achieve over 25% higher seasonal efficiencies than single-speed systems for equal system component efficiencies.

Variable-speed and multiple-compressor heat pumps and central air conditioners have been commercialized; however, market penetration of such systems remains very low to date owing to many factors, including cost, lack of public awareness, and lack of trained installers and service technicians. ORNL worked with DOE, electric utilities, manufacturers, and other stakeholder groups to address these issues, with the goal of expanding the market for high-efficiency systems. One such stakeholder group is the Consortium for Energy Efficiency (CEE). ORNL staff helped CEE develop a set of efficiency tier guidelines for utilities to utilize in setting rebates and other sales incentives for heat pumps and central air conditioners. ORNL participation helped ensure that the tiers gave extra credit to capacity-modulated systems that provide higher seasonal efficiencies for given design point efficiencies.

Besides the work on air-source heat pumps, ORNL has conducted experimental and analytical studies of electric ground-coupled heat pump (GCHP) systems for DOE/OBT. The primary focus of the effort was to develop a technology base to enable the design of systems with lower first cost to the consumer.

Conventional air-source heat pumps use an outdoor air fan coil to extract heat from air for wintertime heating. In summer, heat is ejected through this fan coil to provide cooling for the residence. GCHPs replace the fan coil with a water-source heat pump that circulates a water/antifreeze solution through a buried ground loop. Heat is extracted from the ground for heating in winter and ejected to the ground during cooling in summer. GCHPs are inherently more efficient than conventional electric air-source heat pumps because the ground generally stays warmer than the outside air in winter and cooler in summer.

DOE GCHP research conducted at ORNL followed two paths. First, improved simulation models of the buried ground-loop heat exchanger were developed. These were instrumental in developing improved loop design rules of thumb for northern climates that yield 40 to 50% shorter loops.

Second, an overall system optimization analysis was undertaken to determine a "lowest life cycle cost" system. It was determined that improving the efficiency of the water-source heat pump unit could allow the ground loop to be shortened by about 30% more.

Climatemaster Corporation built two prototype water-source heat pumps with efficiencies more than 25% better than state-of-the-art pumps of the mid-1980s. DOE and Niagara Mohawk Power Company cofunded a field validation study. The prototype units were installed in advanced ground-coupled heat pump (GCHP) systems near Syracuse, New York, and performance was monitored for a year. The performance of these systems was equivalent to that of previously tested GCHP systems using standard water-source heat pumps and much longer ground loops. Energy savings of about \$350 to \$400 per year over conventional air-to-air heat pumps was demonstrated. Because of their shorter ground loops, the advanced GCHP systems had a payback of 2 to 4 years versus the air-to-air systems, whereas GCHPs with standard water-source heat pumps and longer ground loops had 5- to 7-year paybacks. Niagara Mohawk estimated that this improvement would increase sales by 60%.

The GCHP industry has grown considerably since the DOE research was completed. Several manufacturers now offer water-source heat pumps with performance that exceeds that of the prototype units developed under the DOE program. The Electric Power Research Institute has worked with electric utilities to develop incentive programs to reduce the ground loop cost to the consumer even further. For example, the Public Service Company of Indiana worked with a housing developer to preinstall ground loops before home construction started. This provided cost reductions of over \$1,000 per home.

The GCHP market has also grown. In 1985 approximately 5,000 units were being installed in residences per year. Currently, the market installs between 40,000 and 50,000 units per year and is expected to at least double by the end of this decade. Assuming linear growth of GCHP system sales and average unit annual savings of \$375, cumulative savings due to displacement of air-source heat pumps by GCHPs is between \$75 million and \$90 million.

Thermally Activated Heat Pumps. The progress made to date in absorption heat pump efficiency has been substantial, as is illustrated below, and the near-term forecasts for future advances show substantial promise. To further advance the efficiency frontier for thermally activated heat pumps, ORNL has initiated cost-shared R&D projects on second-generation absorption heat pumps using both advanced cycles and advanced working fluids and materials.

A key phase of ORNL's thermally activated heat pump program culminated in the signing of a license agreement between the United Technologies Carrier Corporation, the world's largest manufacturer of HVAC equipment, and Phillips Engineering Company, a small business in St. Joseph, Michigan. The license allows Carrier to commercialize the generator-absorber heat-exchange (GAX) absorption residential heat pump technology that was invented by Phillips Engineering while

HEATING AND COOLING WITH LOW ELECTRIC DEMAND— THE GENERATOR-ABSORBER HEAT EXCHANGE

The generator-absorber heat exchange (GAX) is a breakthrough thermally activated heat pump technology that promises to heat and cool more efficiently, that will last 20 years with minimal maintenance, and that is environmentally benign because it uses neither CFCs nor HCFCs. It is a technology born of a partnership including DOE, a small business in Michigan, a major manufacturer, a national R&D laboratory, and the gas utility industry. Together, they form the basis for the National GAX Heat Pump Program, which also includes the Gas Research Institute and the American Gas Cooling Center. ORNL manages the program for DOE.

Work began in 1982 when DOE requested proposals for the development of new technologies in advanced absorption cycles, one of two primary processes by which thermally activated heat pumps work, the other being engine-driven vapor compression. Phillips Engineering Company, a 25-person firm in St. Joseph, Michigan, delivered the winning proposal for a natural-gas fired, ammonia-cooled heat pump. After 10 years of intense development work supported by DOE, Ben Phillips, the company's president, decided it was time to find a manufacturer for the units.

Carrier began testing the system at its R&D facility in Syracuse, New York, in February 1993. Eight months later, convinced of the design's potential for profitability, Carrier signed a worldwide exclusive license to bring the unit to market. With a concerted effort from the GAX program team, Carrier hopes to have a product available in 1997.

The basic design for what has become the GAX heat pump was first proposed in 1913 by Altenkirch, a German scientist. But no one had successfully developed the concept until the mid-1980s, when Ben Phillips, born in 1912,

operated the first "laboratory breadboard" with DOE/ORNL support.

The Phillips-designed GAX heat pump is notably different from a conventional compressor-based heat pump. It replaces the motor and compressor with a gas-fired generator and an absorber, and therefore requires electricity only for auxiliary devices such as fans and circulation pumps. Fewer moving parts and the absence of a compressor also should lead to lower maintenance costs. The GAX heat pump uses as its refrigerant an ammonia and water mixture instead of CFCs or HCFCs. The generator is actually a distillation column heated by a natural-gas flame. As the ammonia-water mixture within the column heats up, the ammonia is desorbed, or removed. Heat and the chemical reaction of the refrigerant mixture—instead of a motor and compressor—are used to pressurize the vapor, which is then condensed, evaporated, and finally absorbed back into the water, a thermodynamic process that yields heat. The liquid in the absorber is pumped to the condenser pressure by an electric-powered pump and channeled back into the generator column.

Both the absorber and condenser emit heat. The sum of these heat sources equals the heat to be discharged. Another energy-saving feature of the GAX system is shared heat. The hottest part of the absorber is situated next to the coldest part of the generator—the top part, away from the gas flame. This allows absorber heat to heat the cold end of the generator, reducing the amount of heat needed from the flame and saving energy. GAX designers say that the amount of energy required simply to heat a home with today's heat pumps or furnace will be enough to heat and cool with a GAX unit.

under subcontract to ORNL. This technology promises heating efficiency at least 50% better than the best current gas-fired technology and cooling efficiency comparable to electric air conditioning (see highlight).

The GAX residential unit is the first in an absorption system family that DOE and ORNL plan to bring to the market through industry partnerships. Other products will serve the light commercial and large building chiller markets with high cooling efficiency.

Schematic design of the generator-absorber heat-exchange (GAX) heat pump in heating mode operation.

The sale of large commercial absorption chillers was a big business in the United States through the early 1970s, until the "energy crisis" changed fuel price and availability. Also, U.S. manufacturers were virtually without foreign competition and had 100% of the global market until the late 1960s, when the first Japanese manufacturer entered the marketplace. The Japanese manufacturers soon offered both single-effect and the more efficient double-effect chillers, and have continually improved their absorption products throughout the 1970s and 1980s. By comparison, the U.S. manufacturers' main products remained inefficient single-effect chillers that had been developed decades earlier. Although double-effect technology was pioneered in the United States, only one U.S. manufacturer sold a steam-fired double-effect chiller in this country during the 1970s and 1980s. Today, all U.S. manufacturers are selling gas-fired double-effect absorption chillers made under license or imported from Japanese manufacturers. Globally, absorption chillers sales have grown continuously since 1980, and Japanese manufacturers now overwhelmingly dominate world-wide sales.

ORNL, working with the U.S. absorption chiller manufacturers and the U.S. gas industry, have taken the lead in developing the next-generation of absorption chiller, known as "triple-effect." Two different triple-effect chiller technologies, both patented by ORNL scientists, are currently under development (see highlight). A "National Triple-Effect Partnership" has been formed involving ORNL, DOE, Gas Research Institute, and all four U.S. manufacturers of absorption chillers. The National Triple-Effect Partnership, coupled with the U.S. lead in triple-effect technology, is expected to help restore the United States to a competition-leading position in the large and expanding global market for absorption chillers.

NEXT-GENERATION GAS CHILLERS ON THE BRINK OF MARKET INTRODUCTION

Two triple-effect chiller technologies, both patented by ORNL scientists, will soon offer a 50% more efficient cooling performance than the best current gas chiller technology.

In 1988, the dual-loop triple-effect chiller was licensed by Trane. The Trane development and commercialization program, sponsored by the Gas Research Institute, has a 190-ton prototype in operation, with commercialization expected in 1996-97.

In an alternative program, York International is cost-sharing with DOE to develop and commercialize a second triple-effect absorption chiller based on the double-coupled condenser cycle. Market introduction is anticipated in 1997.

A major advantage of both of these products is the use of a "natural refrigerant" (water and lithium bromide) rather than CFCs or HCFCs, which contribute to ozone depletion and global warming.

Refrigeration Systems. ORNL has researched and identified a variety of design changes to supermarket refrigeration systems and home refrigerator/freezer units that have generated significant energy savings. The application of capacity modulation principles and control systems to unequal parallel compressor racks in supermarkets is described in the following highlight.

From 1978 through 1980, ORNL sponsored a research subcontract for DOE/OBT with Columbus Products Company to develop a high-efficiency (energy efficiency ratio, or EER, of 5) compressor for household refrigerators. By making design changes to the motor, suction muffler, and compressor

IMPROVING SUPERMARKET REFRIGERATION

From 1980 through 1982, a DOE/ORNL subcontract involving Foster Miller Incorporated (FMI), H. E. Butt Grocery, and Friedrich Commercial Refrigeration resulted in initial development of an improved-efficiency supermarket refrigeration system. This development involved an unequal parallel compressor rack system and a control scheme to effectively modulate compressor capacity to meet a store's refrigeration load as it changes with time.

In 1982 field trials of the compressor control system at a supermarket in San Antonio, Texas, energy savings of 16% over conventional systems were demonstrated. Subsequent to this DOE/ORNL work, the Electric Power Research Institute sponsored studies involving FMI and manufacturers that resulted in further improvements in the compressor systems and refinement of the control systems. Supermarket energy use reductions of up to 35% have been reported

through use of these concepts. An executive of a leading manufacturer of supermarket systems, notes that "the control algorithms developed under the DOE/ORNL project provided the foundation for the microprocessor controls uniformly installed in new and retrofit supermarket systems since the mid-80s."

Supermarkets account for 4% of U.S. electricity consumption (1.1% of total energy consumption), and about half of of this total is for refrigeration. Today, about 80% of supermarkets use the advanced refrigeration technology, resulting in an average energy savings per store of approximately 30%. The total cumulative energy savings from this technology has been about 0.6 quads since market entry in 1983. Assuming that the DOE/ORNL-developed controls strategy is responsible for about half of this, the project can be credited with 0.3 quads of energy savings, or approximately \$2 billion in cost savings.

REFRIGERATOR/FREEZER ENERGY USE HISTORY AND PROGRAM GOAL

Household refrigerator/freezer energy efficiency improvements

now marketing refrigerator compressors with EERs of 5.2 to 5.5 for use with the coolant R-134a (a replacement for CFC-12). The availability of high-efficiency compressors was a major reason for a decrease in refrigerator energy use (on shipment-weighted-average basis) from about 1,300 kilowatt-hours per year in 1980 to about 900 kilowatt-hours per year in 1990. The availability of improved compressors pioneered by this research effort is responsible for at least half of this improvement.

The average annual energy use of refrigerators in the U.S. housing stock in 1980 was estimated to be about 1,500 kilowatt-hours. New refrigerators were produced at an average rate of about 6.25 million units per year between 1980 and 1990. The estimated cumulative energy savings that resulted from the introduction of refrigerator efficiency improvements during this 10-year period is 150 million kilowatt-hours, or 1.7 quads, which represents a cost savings of about \$12 billion. Improved compressors can claim credit for at least 0.85 quads of this total energy savings, or \$6 billion in cost savings to the American public.

Highly efficient compressors continue to be a key factor in enabling the industry to meet maximum energy use levels (about 700 kilowatt-hours per year on a shipment-weighted basis in 1993), mandated by the National Appliance Energy Conservation Act.

A CRADA with the Appliance Research Consortium of the Association of Home Appliance Manufacturers (AHAM) was initiated in 1992 with the objective of developing and demonstrating a residential CFC-free refrigerator/freezer that consumes at least 50% less energy than mandated by the existing industry standard. AHAM members plan to begin phasing these improvements into their products in 1998. A CRADA with AFEAS, a chemical manufacturers' consortium that developed the "total equivalent warming impact concept," was extended to focus on the global warming impact of nonfluorocarbon technologies and next-generation CFC and HCFC refrigerant replacements.

ORNL is contributing to the industry and government search for and evaluation of replacements for the phaseout of HCFCs. HCFC-22 is the most widely used refrigerant in commercial and residential air-conditioning and heat pump equipment today. Much of the ORNL technology develop-

valve assembly and piston, Columbus Products achieved a 44% improvement over the compressor technology used in refrigerators at the time (EER of 3.5).

The resulting technology was incorporated into a product line manufactured by Greenville Products Company (Kelvinator) of Grand Rapids, Michigan, which produced and sold the refrigerators through the mid-1980s. The technology was then transferred to Americold Compressor Company of Cullman, Alabama. Americold continued improving compressor designs through the 1980s and 1990s and exceeded the performance standard set by the DOE-supported development. It is

CFC/HCFC ALTERNATIVES FOR THE BUILDINGS SECTOR

ORNL is a national leader in CFC/HCFC research. Staff members received ASHRAE Best Paper Awards in 1990, 1991, and 1993 for CFC alternatives screening studies and participated on two United Nations Environment Programme (UNEP) technology panels. One of these award-winning papers described the first documented operational performance measurements of refrigeration systems conducted with hydrofluorocarbons (HFCs), the leading chlorine-free replacement refrigerants. Refrigerants tested included the HFCs R-32, R-134a, R-143a, and R-125, the primary components of the refrigerant blends being investigated as the leading replacements for HCFC-22 and CFC-502.

In 1989, ORNL described the impact of CFC replacement on the energy efficiency of commercial products. This study concluded that with a vigorous research program, most potentially adverse energy impacts could probably be resolved prior to mandated cessation of CFC production. ORNL also organized two workshops in 1987 and 1988 to define a joint industry/government research agenda for foam insulations which led to a multi-year cooperative program. The centerpiece of this program is a series of laboratory and field tests at ORNL's Building Technology Center. The purpose is to show that foams blown with CFC alternatives have performance comparable to those blown with CFCs and to develop accelerated test procedures for the loss of insulation thermal performance over time.

Beginning in 1990, ORNL conducted a major assessment of the relative energy efficiencies, associated carbon dioxide emissions, and net global warming potential of a range of CFC alternatives. This study was conducted for DOE and for the Alternative Fluorocarbon Environmental Acceptability Study (AFEAS), a worldwide consortium of chemical manufacturers. During this work, ORNL defined the concept

of "total equivalent warming impact," which has been widely used by industry and has been cited in several UNEP international assessment reports. A second phase of this study is extending the concept through a rigorous evaluation of nonfluorocarbon-based refrigeration and air-conditioning technologies and substitutes for HCFCs.

Recent ORNL screening projects have identified pure and mixed refrigerant alternatives to CFCs and HCFCs for refrigeration and air-conditioning systems. A new project with Wolverine Tube Company of Decatur, Alabama, is expanding ORNL's extensive experience with heat exchanger design to advanced air-conditioning and heating systems using alternative refrigerants.

The use of CFCs and HCFCs in foam insulations, refrigerators, and heating and cooling systems has been perhaps the single most influential factor in the huge gains in energy efficiency in the buildings sector of the U.S. economy. As the primary DOE laboratory for research on building systems, ORNL has helped to define the performance requirements for current building products that use CFCs and HCFCs. ORNL is working with industry to develop future CFC- and HCFC-free building products that do not sacrifice energy efficiency gains achieved over the past 20 years.

On behalf of the Energy Conservation Subcommittee of the Air-Conditioning and Refrigeration Institute (ARI), Mark Menzer, Vice President of Research & Technology at ARI wrote DOE to express appreciation for ORNL's work on the heat transfer of R-22 substitute refrigerants and the periodic analysis of not-in-kind technologies. He concluded that "The Oak Ridge approach of conducting pre-competitive research, the results of which industry can tailor to its needs, is an example of an excellent government/industry partnership."

MEASURING PARTICLE DRIFT VELOCITY TO IDENTIFY IN SITU REFRIGERANT MIXTURES

The worldwide push to strengthen environmental awareness has given rise to concerns about the destruction of the earth's ozone layer by CFCs, which are used as coolants in air conditioners for automobiles, homes, and businesses and in commercial refrigerant systems, such as those in supermarkets. Because of the heightened recognition that measures should be taken to alleviate the problem of ozone depletion, several major automakers and industrial manufacturers plan to phase out the use of CFCs during the coming decade, opting instead to use HFCs or other coolants that do not contain chlorine.

During the transition, it is particularly important to be able to identify different kinds of refrigerant and coolant mixtures both for regulatory purposes and for proper maintenance and recharging of cooling system equipment. However, no simple instrument has been available to measure the type of coolant originally used in charging refrigerant systems. Now researchers

at ORNL have developed a simple-to-use instrument to accurately measure the percentage of each halogenated compound in refrigerant mixtures. The technology received an R&D 100 Award as one of the top new technology advances for 1992 from *Research & Development* magazine.

The CFC/HFC ratiometer takes advantage of the fact that when an electric source is applied to a refrigerant sample, the refrigerant mixture can easily be electrically charged. The CFC/HFC ratiometer is composed of two major parts. The first employs a pulsed short-wave light source that is shone on a beryllium plate to produce low-energy electrons. The second major part of the instrument measures charged particle drift velocity in an applied electric field. When charged particles are collected, simple electronics for time-to-pulse height conversion measure the collection time. When the calibration curves for various mixtures have been measured, the percentage of each component in gas mixtures can be determined.

The major advantages of the CFC/HFC ratiometer over existing similar products are price and usability. Gas chromatographs, mass spectrometers, and infrared spectrometers are usually bulky and expensive and require skilled operators. The ORNL instrument will be portable, lightweight, and designed to be ready for field use by even a nonskilled person. The push of a few buttons can get the desired results. Its projected cost is around \$1,000, compared to roughly \$5,000 for a gas chromatograph, \$10,000 for a mass spectrometer and \$20,000 for an infrared spectrometer. Patents are now being prepared for the technology, which will then be available for licensing and open to cooperative agreements with industry for further testing on various coolant mixtures.

Fang Chen, C. H. "Winston" Chen and Steve Allman of ORNL, discuss the applications of the CFC/HFC ratiometer, a simple instrument used to measure the composition of refrigerant mixtures. The researchers were awarded a 1992 R&D 100 Award for development of the instrument, which can quickly and accurately identify the composition of refrigerant mixtures in an automobile air conditioner or a home heat pump.

ment work involves application of refrigerant blends, which at this point are the leading HCFC-22 replacement options. The primary focus of ORNL's work in this area is to develop advanced air-refrigerant heat exchanger (HX) designs for use with HCFC alternative refrigerants and blends in the advanced heat pump/central air conditioner systems. To that end ORNL has initiated work with HX and HX tubing manufacturers to develop refrigerant-side surfaces and overall HX configurations to yield maximum thermal performance with zeotropic blends. One or two leading designs will be chosen and manufacturer partners will fabricate HXs for testing in HX calorimeter facilities at ORNL.

A byproduct (and perhaps the most lasting impact) will be the development of advanced design techniques and tools suitable for air-refrigerant HXs using zeotropic refrigerants. An initial HX analysis method for dry and wet (dehumidification) coil performance for both pure and mixed refrigerants has been developed. It will be refined based on experimental data from ORNL and other sources. An initial version of the zeotrope HX code is planned for release to selected industry users for evaluation in late 1995 or early 1996.

ORNL has also developed and patented a technique that extends the liquid overfeed concept to residential air conditioners and heat pumps. The concept, originally developed for application in automobile air conditioners, is described in the highlight on page 47.

EXISTING BUILDINGS

The existing buildings research program supports private and public sector efforts to improve the efficiency of existing residential, commercial, and institutional buildings. Existing buildings are a critical target for achieving reasonable energy and emissions savings in the next 20 years for the buildings sector. Without acceleration and support of prevailing efforts, about 100 years will be required to achieve currently desired emissions reductions in this sector. For example, the sum total of all utility efficiency programs for buildings that have been conducted since the year 1975 might achieve a savings of 2,000 trillion Btu per year in the buildings sector by 2020 if they continue to grow. The focus of the Existing Buildings program is on four R&D efforts:

- improved and validated energy audits; operation, maintenance, and occupant behavior diagnostics, and energy performance verification procedures;
- advanced and improved retrofit technologies;
- improved methods for educating building owners, operators, and occupants about basic requirements and advanced methods for achieving energy efficiency; and
- methods for maintaining savings over the long term.

Program efforts since 1985 have led to current savings of 2 trillion Btu per year, with cumulative savings of 10 trillion Btu (worth about \$75 million), all for a modest level of funding. These energy savings cause a reduction in air emissions of about 32,000 metric tons of carbon equivalent each year (over 150,000 tons total). Important indicators of program impacts include reduced investment requirements for saving energy in the residential sector and the beginning of a major new effort in the commercial sector, based on program results, called Rebuild America. The reduction in residential investment levels is shown in the figure on the next page. The significant reduction in investment costs

Investment costs for energy saved have decreased significantly under the Existing Buildings Program.

REBUILD AMERICA

The Rebuild America program is one of DOE/EE's Energy Partnerships for a Strong Economy. It seeks to stimulate significant capital investments that improve the energy efficiency of existing commercial and large multifamily buildings. The program will provide technical and financial support to enhance the effectiveness of existing programs, build upon and expand utility demand-side management resources, and encourage decision makers to include energy efficiency as an integral part of community renovation and revitalization strategies. A key component of the action will be a solicitation for proposals from individual public and private sector program operators and from innovative partnerships that are able to implement energy efficiency retrofits in large

numbers of commercial and multifamily buildings.

ORNL collaborated in the design of the initiative and contributed significantly to the 1994 program plan. In FY 1995, ORNL will develop technical and marketing materials to assist with the program solicitation. ORNL also will provide technical support for implementation of the winning proposals, including assistance in the provision of guidelines and decision support tools to encourage a whole-building systems approach to energy efficiency commercial retrofits, and guidance on evaluating energy savings and cost-effectiveness.

It is established that Rebuild America will reduce the emissions levels projected for the year 2000 by 1.7 million metric tons of carbon equivalent.

achieved under program direction has led to improvements in many programs of energy utilities and in the National Weatherization Program. The ability of the Existing Buildings Research Program to define requirements for improvements in deployment of retrofit technologies has also led to a major new initiative, Rebuild America. In this new initiative, expected savings by the year 2000 are 100 trillion Btu per year. Program expertise has also led the U.S. Army and the U.S. Air Force to sponsor the development of new guidebooks by the Existing Buildings Program for increasing the energy efficiency of base housing during planned rehabilitation over the next 20 years.

The program has worked with private and public sector organizations all over the country to improve results achieved in building energy efficiency programs, and the program continues to test and sometimes develop new retrofit technologies. Currently, efforts are under way to develop energy audit and diagnostic methods for large programs dealing with hundreds or thousands of buildings because some changes in current practice are needed to deal with larger groups of buildings to obtain benefits from economies of scale.

The program is aiming toward achieving savings of 3,000 to 5,000 trillion Btu annually by the year 2020. This significant savings will depend on continued advancement of program methods such as those pioneered under the Existing Building Program.

TECHNOLOGY TRANSFER

The purpose of the buildings technology transfer program is to ensure that research results are transferred quickly and effectively to private and public sector users. ORNL is working on a DOE team of buildings technology transfer representatives that includes Lawrence Berkeley Laboratory, Pacific Northwest Laboratories, Brookhaven National Laboratory, and the National Renewable Energy Laboratory. This teaming has brought together the expertise of the individual laboratories to promote energy research and accelerate the widespread use of DOE/OBT's R&D findings.

The multi-Laboratory technology transfer team has also linked with the ten DOE regional support offices to share technologies and provide support to regional efforts to promote buildings energy efficiency programs. This group has provided a natural forum for the Federal Energy Management Program to establish contacts with the private sector. In addition, ORNL has partnered with the DOE regional support office in Atlanta to establish a task force that focuses on buildings efficiency in the southeastern United States. The task force includes utilities, universities, state energy offices, non-profit organizations, and private industry.

ORNL has produced many tools and materials that promote technology transfer, including bibliographies, curriculum materials, computerized decision tools, handbooks, proceedings of workshops and conferences, and multimedia programs. One particularly user-friendly tool is the ZIP Code Insulation Program. This program allows a homeowner to enter his or her ZIP code, answer a few questions on an interactive graphic multichoice touch screen computer, and receive cost-effective insulation levels for a new or existing home.

Other ORNL technology transfer projects include the following:

- participating in poster sessions and trade show exhibits;

- presenting papers at major conferences and workshops focused on saving energy in buildings;
- providing technical and management support for the energy-efficient showcase demonstration house to be built in Atlanta, Georgia, during the summer of 1996 to coincide with the next Summer Olympics;
- developing emergency documents to help homeowners deal with rebuilding their homes following water damage;
- providing assistance with market penetration analysis of tools and products; and
- promoting ORNL's Buildings Technology Center to ensure its widespread use.

THE INTERACTIVE ZIP CODE INSULATION PROGRAM (ZIP)

DOE/OBT and the Energy Division at Oak Ridge National Laboratory have co-sponsored development of the Interactive ZIP Code Insulation Program (ZIP). This computer program will inform consumers of cost-effective levels of insulation to install in their existing or planned new homes. The recommendations are based on the calculations of a previous version of ZIP developed by Stephen Peterson at the National Institute of Standards. Southface Energy Institute is developing the computer program for DOE/ORNL.

In developing ZIP, ORNL is seeking to disseminate technical information to a wide variety of audiences nationwide, targeting the homeowner who wishes to reduce energy cost by retrofitting a new or existing home. Outreach venues for the program are building supply outlets, home shows and public events, energy information centers, and energy utility offices. In addition, ZIP will be a useful tool for designers, builders, utility representatives, or energy consultants to use in educating clients about energy options.

The model shows how multimedia computer technology can be used for public energy education. The user employs a touch screen video monitor, enters his or her ZIP code, provides structural information, and progresses through the house. The user will receive a print-out of customized estimates of economical levels of residential insulation. The analysis can be conducted for either new or existing houses. The program currently calculates economical levels of insulation for attic floors, exterior wood-frame and masonry walls, floors over unheated areas, slab floors, and basement and crawl space wells. In addition, by touching rooms and areas in the house on the computer screen, the user will see where energy savings are possible.

The computer program is currently being put into a CD ROM format. It will then be available to the public.

COLLABORATING WITH A HISTORICALLY BLACK UNIVERSITY

The objectives of the DOE/OBT-supported Historically Black College and University (HBCU) Program is to help HBCUs develop a research capability while contributing to DOE's research needs. This is accomplished by assisting institutions in the selection of research topics with a strong engineering or science content, in the preparation of research proposals, and in execution of the work.

In 1988, as part of DOE's HBCU Program, ORNL subcontracted a research project at Tennessee State University (TSU) in support of DOE's Building Equipment Research Program. The objectives of the research are

- to provide an education benefit to graduate and undergraduate students at an HBCU by enhancing the thermal science program in the HVAC area;
- to establish experimental facilities and experience that can support ongoing HVAC research efforts and provide a testing laboratory for private firms with the ultimate goal of becoming self-supporting; and
- to support DOE's research mission through experimental research on the performance characteristics of alternate refrigerants in heat pump cycles.

As a result of this program, a permanent HVAC testing laboratory was established at TSU. A closed-loop water-source heat pump was breadboarded for testing replacement refrigerants for either CFC-22 or CFC-12. D. L. Hinton and Y. Y. Clark, faculty members at TSU, have directed graduate and undergraduate students in characterizing system perfor-

mance for both CFC-22 and CFC-12. TSU has developed a solid baseline of performance for CFC-12 and is in the process of characterizing DuPont's ternary blend of refrigerants for automotive air-conditioning.

Graduate and undergraduate students from TSU have received intensive training at ORNL during summer internships. The experience gleaned at ORNL greatly assisted the students in their respective laboratory tasks at TSU. In addition, Hinton works on a part-time basis with ORNL to develop analytical skills useful to the program objectives. Results of his recently completed study of evaporation characteristics for corrugated tubes were presented at a national meeting of the American Society of Mechanical Engineers (ASME). A companion paper on condensation characteristics for corrugated tubes will be presented at an ASME meeting in 1995.

Graduate student Greg Polk is now employed by Inner City Products, Nashville, and is part of a team developing heat pumps using alternative refrigerants. TSU students Darwin Lyons, Refolder Hennings, and John Owens completed their undergraduate training. Hennings is attending Mississippi State University under assistantship in the Mechanical Engineering Department, while Lyons and Owens are both in industry, employed by Exxon and Alcoa, respectively.

A supplemental heat transfer test stand is now being built that will provide basic heat transfer and pressure drop data and design information for substitute refrigerants. The heat transfer testing capability will enable TSU to conduct work over a broader range of technical problems for the private sector, thereby making its program self-supporting and completing DOE's objectives.

TRANSPORTATION TECHNOLOGIES

The introduction of affordable personal transportation brought massive changes to the United States in the ways that people work and play. Now, transportation has the potential to influence major changes for the second time in this century. A few recent statistics illustrate the huge potential in transportation for beneficially impacting our national economy, national security, global industrial competitiveness, and environment:

- Motor vehicle and equipment manufacturing is the largest of all U.S. manufacturing industries. The U.S. auto industry and auto dealers and suppliers provided over 2 million direct jobs in 1992. More than 13 million people in the United States were employed in all motor vehicle-related industries.
- Transportation consumes two-thirds of the oil used by the United States. In 1992, over 40% of the petroleum used in the United States was imported, and the share of petroleum imports grew in 1993 and 1994. The U.S. trade deficit in 1992 for imported petroleum was \$45 billion.
- The U.S. trade deficit in 1992 for imported cars and parts was \$39 billion. Half of the U.S. trade deficit with Japan in 1992 was caused by motor vehicles and parts.
- In 1991, the United States produced 19% of the world's automobiles, down from 76% in 1950.
- Transportation contributes about one-third of U.S. greenhouse gas emissions.

It is clear that improvements in the energy efficiency and environmental impacts of automobile manufacturing and operation would yield significant decreases in atmospheric pollution and the foreign trade deficit. Funds that now go toward protecting foreign oil interests would be freed for other uses. Recognizing these opportunities for a stronger nation, ORNL designated transportation as a major initiative in 1991 and joined with other DOE Oak Ridge facilities (the Oak Ridge Centers for Manufacturing Technology and the Oak Ridge Environmental Restoration and Waste Management Site) in formation of ORTRAN—the Oak Ridge Transportation Technologies Center. In a related action, ORNL joined with our principal governmental, academic, and industrial partners in the region to form the Tennessee Transportation Technology Coalition, in order to jointly pursue important regional and national opportunities in this field.

The DOE/EE Office of Transportation Technologies (OTT) sponsors programs at ORNL that explore opportunities for increased energy efficiency in transportation. Through research in materials science, ignition and combustion processes, and innovative manufacturing and finishing processes, ORNL provides technologies that enable greater fuel economy and increased use of alternative fuels for transportation. Recognizing the technology base existing at the national laboratories, representatives from General Motors visited ORNL and her sister labs in 1991 to identify research topics of mutual interest. Discussions with Ford and Chrysler soon followed. DOE/OTT saw the need for a focal point between the Big Three automakers and the DOE national laboratories and asked ORNL to take the lead in forming the "C4" Committee to give the automakers efficient access to and coordination with representatives from the laboratories. This high level of cooperation and communication culminated in the declaration of a groundbreaking public-private partnership.

President Clinton and the chief executive officers of General Motors, Chrysler, and Ford at the White House signing ceremony for the Partnership for a New Generation of Vehicles.

"Progress through partnership is a fresh, new and very welcomed way of coordinating and focusing our national efforts to achieve the technological breakthroughs that can make regulatory interventions irrelevant and make our industry more competitive internationally."

*John F. Smith, Jr., President and Chief Executive Officer, General Motors Corporation
September 29, 1993*

PARTNERSHIP FOR A NEW GENERATION OF VEHICLES

On September 29, 1993, President Clinton and Vice President Gore joined with the chief executive officers of the Big Three U.S. automakers to announce the formation of a partnership aimed at strengthening U.S. competitiveness by developing technologies for a new generation of vehicles. The initiative, called the Partnership for a New Generation of Vehicles (PNGV), has three goals:

- To significantly improve national competitiveness in manufacturing. Improvements in manufacturing technologies gained from the Partnership R&D work will be applicable in other manufacturing industries.
- To implement commercially viable innovation from ongoing research on conventional vehicles. The ongoing research focuses on fuel efficiency improvements and emissions reductions. The goal insures that PNGV will build on existing research programs and will apply significant technological advances as they become available.
- To develop a commercially viable midsize car with three times the fuel efficiency of today's comparable vehicle without negatively impacting safety, comfort, purchase and operating cost, or performance, within 10 years.

ORNL is a key player in the PNGV, providing technical support to DOE in program planning and management. Expertise and unique facilities in engine testing, materials development and evaluation, flywheel energy systems, and manufacturing technologies have been drawn from the three Oak Ridge sites (ORNL, the Centers for Manufacturing Technology at the Y-12 Plant, and the Center for Environmental Technology at the K-25 Site) to meet the challenge. ORNL has several ongoing R&D

projects that contribute to PNGV goals. The scope of ORNL's transportation research and development encompasses materials development, alternative fuels issues, propulsion technologies, transportation data, and policy analysis. These are described in more detail in the following sections.

Oak Ridge Technologies Supporting the Partnership for a New Generation of Vehicles

Product

Materials

- Lightweight
- Recyclable/Reusable

Alternative Fuels

- CNG
- Biofuels

Emmision Controls

- Sensors
- On-board Diagnostics
- Engine Support System Technology

Thermal Management

- Smart Glazing
- Efficient Heating & Cooling

Energy Efficient

Propulsion Systems

- Advanced Heat Engines
- Electric Motors
- Fuel Cells

Storage Systems

- Batteries
- Supercapacitors
- Flywheels
- Regenerative Braking

Process

Manufacturing

- Agile Manufacturing
- Rapid Prototyping
- Advanced Technology

Supercomputing

- Design
- Virtual Manufacturing
- Combustion

Technologies supporting the Partnership for a New Generation of Vehicles.

TRANSPORTATION MATERIALS

Ceramic Technology. ORNL's largest project for the DOE/EE Office of Transportation Materials is the Ceramic Technology Project. The original objective of this project was to develop the technology base required to produce reliable ceramics for use in advanced heat engines (e.g., an automotive gas turbine). This goal has been largely met; however, further work is needed to reduce the cost of ceramics before they are economically competitive for a wider range of applications in the transportation sector. The scope of the project has thus been expanded to providing cost-effective ceramics for near-term applications in conventional engines.

Most of the work in the Ceramic Technology Project is being performed by the ceramics industry, with technology support from government laboratories and universities. The technology is being developed in close coordination with the ongoing DOE and industry engine development programs. Working arrangements include cost-shared subcontracts and CRADAs, ensuring that the research agenda meets industry's needs. Project objectives include demonstration of the baseline manufacturing technology for ceramic engine components, completion of casting trials for low-expansion ceramics for exhaust ports in FY 1995, and completion of the development of a ceramic life prediction methodology in FY 1996. A continuing element of the project is maintenance of the Ceramic Technology Project

Database, a unique compilation of information that contains not only engineering test data but also a description of the test methodology and equipment, material characteristics, and photomicrographs. The information in the database is available to all Ceramic Technology Project participants.

The development of "whisker"-reinforced ceramics, in research coordinated with the DOE/EE Advanced Industrial Materials Program and the DOE/Energy Research Basic Energy Sciences Program, was a major breakthrough for the Ceramic Technology Project. Similar to the concept of adobe—where grasses and other fibers are worked into mud to make a composite material stronger than the individual components—whisker-reinforced ceramics are materials in which ceramics are fused with tiny fibers that stop the spread of potentially shattering cracks. Whisker-reinforced ceramics give good strength at high temperatures without the brittleness of conventional ceramics and are finding uses throughout the U.S. manufacturing sector. (See the highlight on "Ceramic Cutting Tools Market Recaptured for American Industry by ORNL Technology.")

USE OF SINTERED SILICON CARBIDE AS A SEAL FACE IN AUTOMOTIVE WATER PUMPS

The DOE Transportation Materials Technology Program, in cooperation with the Carborundum Company, has developed an improved ceramic automotive water pump seal that is now in use in 90% of German automobiles and 30% of U.S. automobiles. The material was developed while the Carborundum Company was a participant in the ORNL Ceramic Technology Project and the HTML User Program. In addition to being extensively tested at ORNL, the material was tested at the University of Dayton and the Army Materials Laboratory, which shared the results concerning fracture mechanisms and microstructural effects with Carborundum. Carborundum used this information to improve its material. Investment in mechanical characterization by DOE/EE's Transportation Materials Technology Program totalled approximately \$500,000 over a 5-year period.

New automotive-engine and truck-engine designs for improved performance, fuel economy, lower emissions, and longer warranties have led to increased operational demands on vehicle cooling systems. Premature water-

pump-seal failures due to "face-filming," a buildup of silicate residues from corrosion inhibitors, and customer demands for extended service have created a need for improved seal-face materials. Due to its superior hardness, high thermal conductivity, and resistance to wear and thermal shock, Carborundum's Hexoloy SA sintered silicon carbide was specified by 90% of German automakers in 1993. While only 5% of U.S. vehicles had silicon carbide seals in 1993, usage increased to 30% in 1994. Silicon carbide seals exhibit roughly one-half to one-third the failure rate of alumina seals.

Carborundum is planning to manufacture and ship 10 million seal faces this year for the combined U.S. and European markets. The potential worldwide market for these seals exceeds \$65 million per year. Manufacture and sales of these silicon carbide water-pump seals will not only help reduce the trade deficit, but also will help achieve one of the goals of the DOE/EE Office of Transportation Materials—the development of cost-efficient propulsion system materials and related processing technologies for automotive applications.

CERAMIC CUTTING TOOLS MARKET RECAPTURED FOR AMERICAN INDUSTRY BY ORNL TECHNOLOGY

Silicon carbide whisker-reinforced alumina ceramics developed at ORNL have had a major impact on the competitiveness of the U.S. machine cutting tool industry. They have increased machining rates by up to 800%, resulting in substantial productivity gains. In addition, they have much lower wear rates, resulting in cost savings from less frequent replacements. These advantages have allowed the United States to recapture a substantial international market share of an industry that was on the verge of disappearing in America in the late 1980s.

The current estimate of the annual worldwide sales of these products is in excess of \$30 million, creating about 300 new jobs. The composite material is used as machine tool inserts (e.g., cutting tips, drills) for machining metals and wood products and for tooling in metal-forming operations (e.g., beverage and food can stamping dies). Advanced Composite

Materials Corporation, Cercom, Inc., Dow Chemical Company, GTE, Hertel Cutting Technology, Inc., Kennametal, Inc., Keramont Corporation, and Valenite Corporation hold licenses

for this ORNL-patented ceramic. The rapid growth of several smaller companies in this market is due principally to the widespread use of these whisker-reinforced materials in the products they sell.

Whisker-reinforced ceramics were developed in coordinated DOE programs, including the OTT/Transportation Materials Technology Ceramics Exchange, Energy Research's Office of Basic Energy Sci-

ences, and the Office of Industrial Technology(OIT)/Advanced Industrial Concepts Program (formerly the Energy Conversion and Utilization Technology Program). The Transportation Materials Technology Ceramics Program invested \$3.8 million over 7 years in developing this composite material.

Industry is finding uses for silicon carbide whisker-toughened ceramics, from automobile parts to cutting tools for manufacturing.

The Ceramic Technology Project has contributed to the creation of numerous ceramic products, including cutting tools made from silicon carbide whisker-reinforced aluminum oxide, improved automotive water pump seals made from a new silicon carbide ceramic called Hexoloy SA, prototype engine components from silicon nitride, piston rings manufactured from a proprietary ceramic composition, and auxiliary power units, rocket engine turbine pumps, and industrial gas turbines manufactured from in situ toughened silicon nitride. Several of these are highlighted below.

SUPER GRIP FOR TENSILE TESTING OF CERAMICS

A gripping device for tensile testing of ceramics was developed by ORNL scientists in the Ceramic Technology Project. The invention was licensed to Instron Corporation, a supplier of testing machines, which has sold approximately 75 Super Grip-equipped machines thus far, accounting for approximately \$7.5 million in sales.

The Super Grip makes possible tensile testing of ceramics, to provide critically needed data for applications such as advanced heat engines. Before this development, it was not practical to test ceramics in tension, and these vital data were not available to designers and users of advanced ceramics. The availability of testing machines with Super Grips has had a revo-

lutionary effect on the testing of advanced ceramics and is accelerating the commercialization of ceramic components in heat engines and other engineering applications.

In a related effort, ORNL has worked with U.S. industry participants in an International Energy Agency program to develop testing standards for the tensile testing of ceramics, to facilitate international trade. A U.S. standard has been developed and is in the approval process in the American Society of Testing and Materials. The invention and development of Super Grips was accomplished for an investment of \$1 million over 4 years. The interlaboratory testing to develop standard testing methods required an additional \$1 million over 9 years.

CHAND KARE TECHNICAL CERAMICS—A MINORITY-OWNED SMALL BUSINESS

The DOE Transportation Materials Technology Program plays a significant role in assisting small advanced materials companies in becoming competitive. Many of the program's subcontractors, HTML users, CRADA partners, and collaborators are small businesses.

One such business is Chand Kare Technical Ceramics, a minority-owned small business, which conducted research at ORNL with funding from the DOE Transportation Materials Technology Ceramics Program. Chand Kare was an HTML user, a subcontractor, and a CRADA partner in the Transportation Materials Technology Ceramic Program. Through these programs Chand Kare identified condi-

tions under which flaws were introduced in ceramic workpieces by its machining practices. The company was then able to modify its machining conditions to reduce the size of flaws and hence produce components with superior properties, leading to increased business.

The process improvements that resulted from Chand Kare's Oak Ridge research have led to substantial growth of this U.S. company. From 1990 to 1994, while participating in the DOE program, Chand Kare more than doubled in size, from 30 to 75 people, increased sales from about \$3 million to \$8 million, and opened two additional facilities resulting in a total of three plants. The DOE investment was approximately \$400,000 over a 4-year period.

COORS CERAMICS COMPANY

President George Bush, Governor Lamar Alexander, and ORNL Director Alvin Trivelpiece observe Joe Coors signing a CRADA at ORNL.

Coors Ceramics Company and its R&D subsidiary, Golden Technologies, Inc., were the first participants in DOE's joint Energy Efficiency and Renewable Energy-Defense Program's Cost-Effective Machining of Ceramics program. Coors' participation in this program led to the improved production of ceramic electronic substrates, development of a low-cost silicon nitride material for applications in automotive engines, and development of low-cost, high-performance zirconia ceramics for many applications. Coors built a plant in Oak Ridge, Tennessee, to be closer to the technologies developed at ORNL, including the HTML. The Oak Ridge Coors plant currently employs 150 people and has annual sales of \$23 million.

President Bush traveled to Oak Ridge along with Energy Secretary Watkins to witness the signing of an agreement with Coors. That successful program has resulted in the development of in-process inspections of product quality that allow for real-time adjustment of the pro-

cess to reduce scrap and improve product quality and efficiency. Coors expects to realize a significant improvement in product quality, yield, and efficiency via the utilization of the in-process inspections. The technology is now being extended to the production of engine components for advanced diesel engines.

Coors formed an alliance with Eaton Corporation to develop ceramic engine components. Coors licensed a low-cost process for making silicon nitride ceramics from Eaton and scaled up the process in a Ceramic Technology

Project task. Coors is now producing prototype engine components for Detroit Diesel Company. Coors components have been tested in diesel engine rigs for more than 500 hours without a failure of the ceramic components. In a related Ceramic Technology Project task, Golden Technologies is developing advanced manufacturing technology to lower the cost of the ceramic components and make the components cost competitive with metal parts.

Coors took advantage of an extensive database of mechanical property data on zirconia ceramics developed in the Ceramic Technology Project by universities and ORNL to develop a product line of zirconia ceramics. The company produces approximately 300 tons of zirconia annually for many technical applications.

The Ceramic Technology Project has invested approximately \$5 million in the Coors technologies over a 5-year period.

TECHNOLOGY TRANSFER—WITH A PERSONAL TOUCH

When Secretary of Energy Hazel O'Leary toured ORNL last April, she visited the HTML and met Ogbemi Omatete, a researcher in the Metals and Ceramics Division on hand to display some of ORNL's successes

ORNL researcher Ogbemi Omatete shows a gelcast turbine to Secretary of Energy Hazel O'Leary and U.S. Representative Marilyn Lloyd.

with gelcast ceramic materials. She also learned of an arrangement for Omatete to work with an industrial firm interested in the manufacturing process. The firm was AlliedSignal Ceramic Components, which makes a silicon nitride turbine for aircraft auxiliary power units that provide power to an aircraft as it idles on the tarmac, or in emergencies such as engine failure.

Some years ago, Metals and Ceramics Division researchers developed a gelcasting pro-

cess for manufacturing ceramic parts. AlliedSignal Ceramic Components was investigating different methods for casting its turbines and became interested in gelcasting. AlliedSignal requested that a Lab researcher come to their facilities for a few months to work on a joint AlliedSignal/ORNL project. After working out the administrative details, the visit began in early 1994. Both sides see the story as a success. According to Doug Craig, director of ORNL's Metals and Ceramics Division, "We wanted to show that gelcasting would work with commercial techniques in an industrial setting. It worked out very, very well." AlliedSignal's general manager Maxine Savitz wrote that Omatete's "daily interaction was invaluable and has accelerated the application of gelcasting as a potential manufacturing process at Ceramic Components." AlliedSignal Ceramic Components has since licensed gelcasting for use in making silicon nitride turbine blades and other complex ceramic components.

ORNL hopes that more scientists will be visiting industrial laboratories under arrangements similar to the one that worked out so well for ORNL and AlliedSignal. "This is certainly something we want to do more of—both sending Lab people out to places and bringing people to the Lab," Craig said. "These interactions give us an important industry perspective on issues like cost and manufacturability."

Lightweight Materials. Lightweight materials have a direct impact on improving vehicle economy. Heavier vehicles require more energy for accelerating and maintaining speed, and dissipate more braking energy for stopping. It is estimated that a 25% weight reduction in current vehicles would save about 13% of the total U.S. gasoline consumption and would reduce carbon dioxide emissions by about 101 million tons per year. Although there are many lightweight materials, such as aluminum, titanium, magnesium, polymer, and polymer matrix composites, use of these materials in vehicles has been limited because they are much more expensive than steel. Increased recycling of automobiles is a PNGV objective, and these materials also present challenges in that regard.

The ORNL Lightweight Materials Program has two goals: to develop cost-effective materials and technologies that will aid in automobile weight reduction while meeting or exceeding safety standards, and to reduce the automobile's overall environmental impact by process waste minimization and

increased "recyclability." ORNL, in concert with the U. S. Automotive Materials Partnership (USAMP), has drawn up a multiyear plan to serve as a road map for the parties trying to achieve those goals. USAMP is a consortium made up of the Big Three automobile manufacturers and their suppliers. Most of the work is to be carried out through CRADAs. Long-term R&D needs identified by USAMP are being addressed, especially process modeling, light metals casting, material performance modeling, polymer composites manufacturing, and composite durability.

Alternate Processing

Microwave processing shows promise for increasing strength of adhesion while lowering processing times.

As part of the work on lightweight materials, a cooperative effort with the USAMP Automotive Composites Consortium is under way to develop and demonstrate reliable adhesion technologies for lightweight composite and metal automotive structures. The bonding of similar and dissimilar materials was identified as being of primary importance to the consortium, since this frees designers to choose from an expanded menu of low-mass materials. ORNL leads three tasks for the project: development of standardized test procedures for determining fracture behavior of adhesive joints; generation of computer models for prediction of joint failures; and advanced technologies for designing, curing, and manufacturing adhesive joints. Within the next 2 years, a demonstration project will be completed in which about one-half of a vehicle will be made of an automotive-grade composite that will be adhesively bonded together, and to the rest of the vehicle; the vehicle will then be tested for durability using standard industry test procedures. Success will depend on meeting manufacturability time and cost goals so that the technology can be readily incorporated into production lines.

Alternative Fuels Materials Issues. In other work for the DOE/EE Office of Transportation Materials, ORNL

has examined materials problems in engines and vehicle systems due to the use of alternative fuels, as well as infrastructure needs for delivering alternative fuels to consumers. A technology needs assessment and a draft multiyear program plan were completed for DOE. A study of the durability of all-composite cylinders for compressed natural gas is nearly complete. As natural gas-fueled vehicles hit the road, the fuel cylinders will be exposed to harsh environmental factors that can limit their durability. This project will help to define the safe limits.

Tribology. ORNL is completing two CRADAs to evaluate the friction and wear of carbon graphite and in situ-reinforced silicon nitride materials. The tribology project has yielded important and unique data for the Ceramic Technology Project and other DOE/EE Transportation and Industrial Materials programs.

ALTERNATIVE FUELS

Biofuels Feedstock Development. Alternative-fuel vehicles offer both potentially lowered emissions and freedom from dependence on petroleum for transportation. Biomass-plant matter such

as leaves or stems-can be converted to alcohol fuels to power vehicles. ORNL manages DOE's Biofuels Feedstock Development Program (BFDP), a national program for the development and demonstration of environmentally acceptable, commercially viable biomass supply systems based on energy crops. The program's areas of emphasis include wood and herbaceous (grass) energy species; environmental research; systems integration and analysis; scale-up, feasibility, and demonstration; and data and information management. The program includes research by universities, the U.S. Department of Agriculture, and industry collaborators. It is closely coordinated with research programs at the National Renewable Energy Laboratory which are developing new processes for converting plant biomass to fuels. Although the primary focus is transportation biofuels, biomass can also be used in the generation of electricity. ORNL also works with DOE's Office of Utility Technologies, the Electric Power Research Institute, and utilities on technology needs and the feasibility of co-firing biomass and coal, or of completely replacing coal feedstocks with biomass.

The BDFP's energy crop development has emphasized selection, characterization, and improvement through breeding and genetic studies. Poplars have been selected as the model woody energy plant species for the Pacific Northwest, Southeast, and North Central regions of the United States.

On an American farm of the future, products will include traditional food, feed, and fiber, as well as electricity, fuels, and chemicals.

Working with universities, industry, and the U.S. Department of Agriculture, the BDFP has efforts under way in each of these regions to breed poplars for increased yield, pest and disease resistance, and drought tolerance. Switchgrass has been selected as the model herbaceous energy crop species. It is a productive, long-lived native plant that can be grown across most of the United States east of the Rocky Mountains. Five universities and the U.S. Department of Agriculture are collaborating with ORNL in breeding new switchgrass varieties for energy crops in the South and in the Great Plains. The best of the existing varieties for energy applications will be selected in 1996. Large-

scale field trials on new varieties are scheduled to begin in 1997 across the South.

Poplar Breeding Success. In the Pacific Northwest, two poplar species, *Populus deltoides* and *Populus trichocarpa*, were crossed to produce a hybrid poplar that exhibits increased vigor and yield. The leaves of the hybrid plants are about four times as large as the leaves of parent plants of similar age. These hybrids are now being grown commercially by three forest products companies in the Pacific Northwest. A CRADA with Boise Cascade is under way to evaluate biochemical indicators for drought tolerance in the hybrid poplars. This study uses the hybrids in the largest field irrigation experiment ever established for hardwood species in the United States. The program's newest poplar breeding project, in the Southeast, includes three university and seven industrial participants in broad field trials. Breeding of poplars for the North Central region is an ongoing effort that includes the USDA-Forest Service and four universities. Insect-resistant and disease-resistant clones will be tested across a four-state region beginning in 1995, and are scheduled for public release between 1998 and 2002.

The BDFP is also concerned with environmental effects and the integration of energy crops

Poplar breeding efforts have significantly increased biomass yield. The large leaf on the right is from a hybrid cross of two parent poplar species, represented by the two smaller leaves (left and center).

scape ecology, water quality, and water balances.

Alternative Fuels Utilization. ORNL also performs R&D on the implications of alternative fuel use for engines, ignition systems, and emissions control systems. In the Alternative Fuels Utilization Program, a CRADA on improved catalyst materials and emission control systems is under way with General Motors, AC Delco Systems, the largest manufacturer of automotive catalytic converters in the world. (The CRADA is co-sponsored by the ORNL Advanced Industrial Materials Program and the DOE/EE Office of Industrial Technologies.) Catalysts for natural gas and alcohol fuels are emphasized along with conventional fuels, and the R&D includes materials characterization, bench tests, and detailed measurements of catalyst performance on engine test stands. This project will help to elucidate the mechanisms of catalyst degradation—a critical factor to AC Delco Systems because of mandates to produce emission control systems durable enough for 100,000 miles of service.

Successful completion of this project will help General Motors maintain world market share with economically competitive and durable catalytic converters.

into the fuel and farm economies. Energy crops must be profitable for the farmer and economically competitive with other sources of fuel. In addition, they should not incur environmental costs that exceed those of current crops. Lower environmental impacts are preferable, and appear possible. ORNL has just completed a study, co-sponsored by the Tennessee Valley Authority, that determined the costs and environmental impacts of producing energy crops in the Tennessee Valley and surrounding region. An integrated analysis is quantifying and characterizing the potential production of energy crops for an 11-state region across the South and Midwest. The results from regional economic analyses will provide information for an examination of the impacts of energy crops on regional land-

The engine test facility used for catalyst research. The facility, part of the Oak Ridge Centers for Manufacturing Technology, is capable of performing automated and precisely controlled testing under steady-state conditions or programmed transient speed/torque profiles emulating a Federal Test Procedure cycle for vehicles.

Bioreactors for Alcohol Fuel Production. ORNL has exciting ideas for the production of alternative fuels. A new project utilizes a fluidized-bed bioreactor to produce alcohols that can be used as transportation fuel. The fluidized-bed bioreactor can operate continuously, producing alcohols and simultaneously separating them from the production by-products. The project staff have been working with one industrial firm to complete an initial trial run for ethanol production, and have entered into discussions with another firm regarding their involvement in additional pilot and larger-scale trials. Both ethanol producers and suppliers of fermentation agents (enzymes and bacteria) have shown interest in the project. A project that is still under consideration for future funding will involve designing and demonstrating an integrated system utilizing bioreactors that will convert wastepaper to ethanol.

PROPULSION SYSTEMS

Automotive Propulsion Technology. The Automotive Propulsion Technology Program complements ORNL's work on alternative fuels utilization by examining and testing concepts for advanced engines. ORNL provides field management for heavy-duty (truck) engine emission aftertreatment and alternative fuel technology. Specific research tasks include development and assessment of technologies for control of nitrous oxide emissions, development of materials for a diesel engine particulate trap/filter, and improvements in ignition and combustion for natural gas- and alcohol-fueled engines. A small business working with Detroit Diesel Corporation and ORNL has developed a new type of glow plug that improves the performance of natural gas engines. (A glow plug is a special type of spark plug used in diesel engines.) The ceramic glow plug utilizes a high-temperature ceramic in the heating element part of the plug. The ceramic heats faster and has a higher temperature capability than conventional glow plugs. It is expected that the ceramic glow plug will improve cold-start capability, enhance fuel combustion and thus engine performance, and provide longer service life.

Environmental Control Technology. The environmental control technology project investigates space conditioning systems that are nonpolluting, cost-effective, and energy-efficient. A new application arising from this research is the liquid-overfeed mobile air conditioner which is 20% more energy-efficient than existing air conditioners and uses non-chlorofluorocarbon refrigerants (see the highlight "Cooling Cars for Less"). The liquid overfeed air conditioner is made possible by an advanced heat exchange device that was developed by ORNL during research into the thermal sciences.

TRANSPORTATION DATA AND POLICY ANALYSIS

ORNL provides support to the DOE/EE Office of Transportation Technologies through analyses of transportation data and energy use related to vehicle and engine research and development, and fuel economy, sales, and technology trends.

The *Transportation Energy Data Book* is a statistical compendium prepared and published annually by ORNL. Designed as a desktop reference, the data book assembles statistics characterizing transportation activity and presents information on other factors that influence transportation energy use. Its purpose is to enable informed decision-making about transportation-related issues by presenting relevant statistical data in the form of tables and graphs. For example, the figure shows trends in U.S. petroleum production, consumption, and transportation use over the past 20 years. Each of the major transportation modes—highway, air, water, rail, and pipeline—is treated in a separate chapter. The *Transportation Energy Data Book* is internationally recognized as a primary source for transportation

COOLING CARS FOR LESS

ORNL scientists have invented a heat-exchange device that increases the efficiency of automobile air conditioners by 20%, cuts fuel consumption, and could lengthen the life of the cooling unit.

"For every ten dollars normally spent running the air conditioner, two dollars will be saved," said Fang Chen, leader of ORNL's thermal and environmental technology group in the Laboratory's Energy Division.

The patented new design, created by Chen and ORNL colleague Vince

Mei, is compatible for use with coolants that do not contain chlorofluorocarbons (CFCs), which are believed to contribute to ozone depletion in the upper atmosphere and are being phased out.

If the design is fully implemented in the U.S. auto industry, the increased energy efficiency could save about 340 million gallons of fuel a year nationwide and could cut annual carbon dioxide emissions by more than 6.5 billion pounds. Annual fuel cost savings to the consumer would exceed \$400 million a year at a fuel price of \$1.20 per gallon. Through the Martin Marietta Energy Systems Office of Technology Transfer, ORNL is now talking with U.S. automakers and with air-conditioner manufacturers about licensing the technology.

The improvement involves adding a

ORNL researcher Vince Mei examines the liquid overfeed air conditioner prototype on a test stand.

simple, inexpensive heat-exchange device to existing air-conditioner designs. The device allows the coils in an air conditioner's evaporator to be "overfed" with liquid coolant, which increases cooling capacity. Any excess liquid coolant exiting the evaporator is rerouted back into the same heat exchanger for vaporization, protecting the unit's compressor and decreasing its workload, which lowers energy consumption.

The efficiency boost and the associated savings may be applicable to home air-conditioning units, an investment that each year could save consumers \$4 billion in energy costs and cut carbon dioxide output by 21 billion pounds. Further studies to apply the technology to stationary air conditioners, home heat pumps, and refrigerators are pending.

data, with users including the U.S. Congress, the automobile industry, numerous federal and state government agencies, regulatory boards, and foreign government and research institutes. DOE used data contained in this publication to help develop the National Energy Strategy.

Petroleum production, consumption, and transportation use in the United States from 1970 to 1993.

ORNL also provides support to the DOE Office of Policy, Planning and Program Evaluation in collaborative efforts to analyze energy policy options related to increasing transportation energy efficiency and the introduction of alternative fuels into the marketplace. In one such collaborative effort, a static equilibrium model of alternative fuel and vehicle choice contributes to an ongoing DOE study on the costs and benefits of alternative fuel use in the U.S. transportation sector. Another recent study examined the relationships between urban travel and urban spatial structure. A key conclusion of this study is that to design effective and sustainable vehicle travel reduction policies, policymakers must deal both with the physical layout of the nation's geographically expanding cities and with the increasingly mobile urban population.

Staff from ORNL's Center for Transportation Analysis have also examined the energy, emissions, and social consequences of telecommuting. They found that substantial levels of telecommuting would provide a significant decrease in transportation petroleum consumption, despite offsetting effects such as increased urban sprawl (see the highlight "Telecommuting—A New Way to Get to Work").

TELECOMMUTING—A NEW WAY TO GET TO WORK

Substantially increased levels of telecommuting can produce significant benefits in the form of reduced traffic delays, motor fuel consumption, highway capacity expansion requirements, and emissions. Telecommuters will reduce their transportation fuel use and vehicle emissions because they will be driving fewer miles. However, these positive direct effects of telecommuting will be both offset and supplemented by the indirect effects of telecommuting—the results of the various other transportation-related changes that are likely to occur as telecommuting becomes more and more widespread. These indirect effects are the following:

- **Improved Traffic Flow.** Because of reduced congestion, the remaining vehicles on the highway will operate more efficiently. Better traffic flow and fewer stops and starts will reduce fuel use and emissions.
- **Latent Demand.** People who previously avoided using their vehicles because traffic was too congested will start driving more because telecommuting has lessened this congestion. This will tend to offset the direct reductions in fuel use and emissions.
- **Increased Urban Sprawl.** As close proximity to a central workplace diminishes in importance, telecommuters will feel freer to live farther from urban centers. This geographic expansion of cities will lead to longer drives when these workers do use their vehicles, and it will require additional highway construction.

The study indicates that the energy and emissions benefits of telecommuting are not likely to be entirely offset by latent travel demand or by the geographical expansion of cit-

ies. Perhaps half the potential reduction in vehicle-miles traveled (VMT) directly attributable to telecommuters will be replaced by new traffic, induced by lower levels of congestion and higher average speeds. But reduced congestion and higher speeds will create indirect benefits in terms of lower average emissions and fuel consumption rates. From a fuel-use perspective, this indirect benefit appears sufficient to offset impacts from the third indirect effect, additional travel brought about by increased suburbanization.

Thus, for vehicle travel and fuel use, the overall combined indirect effects of telecommuting appear to offset about half of the direct benefits. This estimate varies depending on the specific assumptions made regarding the effects of telecommuting on highway capacity expansion, latent demand, and urban sprawl. However, in no case do the benefits of telecommuting completely disappear. The figure depicts the potential energy impacts of telecommuting, including the direct and indirect effects included in this study.

Direct and indirect effects of telecommuting on fuel consumption under DOE "alternative" scenario, year 2010 (billion gallons of gasoline).

INDUSTRIAL TECHNOLOGIES

America's industries consumed 39% of the nation's end-use energy in 1990. A small number of major manufacturing groups (primary metals, petroleum refining, chemicals, pulp and paper) account for about 70% of this industrial energy use, or about 27% of the nation's total energy use. The DOE/EE Office of Industrial Technologies (OIT) has begun an initiative to work with these industries to cut their nonproductive energy use and environmental costs. Called "Industries of the Future," the initiative is targeted at the steel, aluminum, foundry, petroleum refining, chemicals production, pulp and paper, and glass industries. The research programs will be developed by the industries and will be jointly executed by industry, universities, and national laboratories.

ORNL has made technological advances that are contributing to improved industrial efficiency through decreased energy consumption, improved product quality, reduced equipment downtime, and decreased waste streams. As industry expenditures on nonproductive costs decrease, resources are made available for market expansion and investment in plant and capital equipment. ORNL's goal in research for the DOE/EE Office of Industrial Technologies is to assist U.S. industry in capturing and maintaining global market share through technological improvements.

ADVANCED MATERIALS AND MANUFACTURING TECHNOLOGIES

Advanced Industrial Materials. The Advanced Industrial Materials (AIM) Program develops new and improved materials and manufacturing technologies leading to more efficient use of energy in support of the Industries of the Future initiative in the Office of Industrial Technologies. High-temperature intermetallic and metallic alloys with high ductility, corrosion resistance, and strength are being developed. Metal-bonded composites are being developed for optimal use at temperatures between those of currently available alloys and ceramics. Coatings and engineered porous materials are being evaluated for various applications. Microwave technology is being pursued because it offers new and exciting potential for materials with unique properties. Recently, ORNL has participated in an activity focused on performing materials needs and opportunities assessments for the pulp and paper industry. This effort—which includes participants from industry, universities, institutes, other national laboratories, and DOE—has resulted in projects aimed at developing improved materials to meet the identified needs of the pulp and paper industry.

One of the most successful ORNL inventions resulting from the AIM Program is ordered intermetallic alloys, which were developed in a cooperative project with the DOE Office of Basic Energy Sciences. Ordered intermetallic alloys are different in atomic structure from conventional alloys, and the atomic structure can be optimized for specific applications. One of the most successful of the ordered intermetallic alloys is nickel aluminide. Seven industrial firms have held exclusive and nonexclusive licenses to the material, and optimization for commercial applications is the subject of several CRADAs (see the highlight "Nickel Aluminide Alloy Finds Commercial Application in the Steel and Die-Making Industries").

A project at the Georgia Institute of Technology has successfully demonstrated the feasibility of producing monosize hollow spheres of many ceramic compositions on a production basis. The mechanical strength and thermal conductivity of the spheres have been documented, and mathematical modeling of the sphere-forming process has been successful. The technology, trademarked

NICKEL ALUMINIDE ALLOY FINDS COMMERCIAL APPLICATIONS IN THE STEEL AND DIE-MAKING INDUSTRIES

In a CRADA with a small business called Metallamics, nickel aluminides are being developed as roller material in heat-treating furnaces used in the production of plate steel. The objective is to produce a roll material that will prevent scratching of the plates as they move over the rolls and offer longer service life than current materials. Field trials in a steel mill furnace are being conducted with promising results; Metallamics expects to fully commercialize the technology by June 1996. ORNL is aware of at least four steel companies that are waiting to install the rolls when they are available. The companies expect to recoup their investment in nickel aluminide rolls through decreased furnace downtime, improved product quality, and energy savings.

In a CRADA with Rapid Technologies, Bimac, and the DOE Office of Basic Energy Sciences, nickel aluminides are being made into walking-beam furnace rails. The rails must resist oxidation and have good high-temperature strength. Commercialization is expected by the end of 1995. Bimac and Rapid Technologies expect that the increased operating temperatures possible in furnaces through use of nickel aluminides will save 1 trillion Btu of energy over

2 years, with attendant decreases in carbon dioxide emissions.

Fixtures for use in carburizing heat-treating furnaces are being made from nickel aluminides. A CRADA with General Motors focuses on fixture manufacture and testing under production conditions, and commercialization is expected by June 1996. If the trial results continue to be encouraging, General Motors plans to completely replace its current furnace fixture material with nickel aluminide. In addition, several other companies have expressed interest in the application.

A more unusual application for nickel aluminide is as a die material for rare-earth magnets. Magnet disks are hot-pressed from the dies; nickel aluminide is the only material known to possess the required high-temperature strength and to be compatible with the rare-earth compound. This application has been fully commercialized in cooperation with General Motors and Metallamics (the rare earth compound, NdFeB, was developed at General Motors). The dies are part of a license that General Motors offers to other companies, and they have been licensed to companies in Germany.

Nickel aluminides offer savings for high-temperature applications, such as furnace fixtures (left) and rollers (right).

Aerospheres™, makes it possible to form hollow spheres from dispersions of inexpensive ceramic powders, engineer the sphere wall to minimize heat conduction, and bond the spheres into structural monoliths, such as the example shown here. Applications include structural insulation, radiant gas burners, liquid metal filters, low mass kiln furniture, and particulate filters. Significant discussions are ongoing with the Gas Research Institute in the area of radiant burners and with an electronics company for kiln furniture. In addition, tests with a major electronic equipment supplier have shown that aerosphere insulation works well in the vacuum/corrosive gas environment used for thin film continuous vapor deposition.

STRUCTURAL INSULATION from AEROSPHERE FOAMS

➡ Hollow Ceramic Spheres

➡ Furnace Insulation for Y-12 Plant

➡ Point Contact Bonded Hollow Sphere Foams

Structural insulation from Aerosphere™ foams.

Continuous Fiber Ceramic Composites. The Continuous Fiber Ceramic Composite (CFCC) program focuses on development of processing methods for fabrication of CFCC components for industrial applications. CFCCs offer high-temperature stability, corrosion resistance, and light weight; and they have the potential for providing significant energy and environmental benefit to U.S. industry. High-efficiency, high-temperature heat exchangers and gas turbines made with CFCCs could save U.S. industry as much as \$2 billion per year in energy costs. Annual nitrous oxide emissions from industries could be cut as much as 917,000 tons, and annual carbon dioxide emissions by 118 million tons.

The CFCC development program is being implemented through joint projects with industry. ORNL provides technical assistance in project evaluation and industry interaction, as well as an R&D program that provides improved technologies for the design, development, fabrication, and characterization of composite materials to meet different needs, including the development of methods for testing these new materials. An example of one of these joint projects is provided in the highlight "Advanced Ceramic Composite Material for Industrial Gas Turbine Combustor Liners—The GE Team's Approach."

Advanced Bioprocessing Concepts. ORNL investigates the separation and processing of industrial chemicals using advanced bioprocessing concepts. The focus is on innovative bioprocesses that can exploit renewable resources such as corn sugars, woody biomass, or even carbon dioxide or water, for the production of fuels and chemicals. These advanced bioreactors can be used in aqueous, gaseous, and nonaqueous systems. Columnar bioreactors have the potential for significant increases in volumetric productivity, perhaps as much as a tenfold increase over conventional technologies (see highlight "Fluidized-Bed Bioreactor Economics Look Good").

Much of the work on advanced bioprocessing concepts takes place in the Bioprocessing Research and Development Center and employs the equipment of the Bioprocessing Research User Facility described in Chapter 1. The center was established in 1991 to capitalize on ORNL's pioneering

ADVANCED CERAMIC COMPOSITE MATERIAL FOR INDUSTRIAL GAS TURBINE COMBUSTOR LINERS—THE GE TEAM'S APPROACH

A team led by GE Corporate Research and Development, based in Schenectady, New York, is developing a ceramic composite material, Toughened Silcomp™, for use in land-based gas turbine engines. Toughened Silcomp consists of silicon carbide fibers in a matrix of silicon carbide and silicon, and is made by a melt infiltration process using processing times on the order of minutes. This process can be used to produce fully dense, complex shaped parts with controlled fiber architecture. The fully dense matrix gives Toughened Silcomp composites good oxidation resistance, high thermal conductivity, low thermal expansion, and good interlaminar strength.

During the initial, exploratory phase of the program, a number of material and process improvements were made, including (1) the development of a semicontinuous process for preform fabrication capable of being scaled; (2) the successful use of an oxidation-resistant fiber coating; and (3) improvements in matrix cracking and ultimate strengths of up to about 20% and 100%, respectively. The design analysis indicated that Toughened Silcomp is well suited for gas turbine combustor and shroud applications. Plans for the second phase of the program are to further modify Toughened Silcomp

to improve its long-term stability and oxidation resistance, to develop a mechanical property database on the optimized material, to establish two vendors (Textron Specialty Materials and Carborundum Company) for fabrication of representative combustor and shroud components, and to evaluate these components using rig tests that represent actual component use conditions.

The GE team (including Textron Specialty Materials, Carborundum Company, and ORNL) will develop and demonstrate the use of Toughened Silcomp for combustor liner and shroud applications in industrial gas turbines. Current turbines utilize 30 to 40% of compressor discharge air for component cooling purposes. The use of CFCC components, which have higher temperature capabilities than current superalloys, would allow a reduction in this cooling air. Redirecting this extra cooling air through the combustor and turbine will allow the engine to operate at a higher cycle efficiency, reducing fuel consumption and/or increasing power output, while simultaneously reducing undesirable emissions of unburned hydrocarbons, carbon monoxide, and nitrogen oxide. The use of CFCC shrouds and combustors would alone result in nearly \$1 million per year in fuel savings for a 7FA class machine.

A 4-inch-diameter by 4-inch-long cylinder of Toughened Silcomp™ fabricated in Phase I to demonstrate the feasibility of making cylindrical components, such as industrial gas turbine combustor liners.

MATERIALS ABSORB "MAGIC FREQUENCIES" IN REVOLUTIONARY MICROWAVE FURNACE

Researchers at ORNL have invented and developed a variable-frequency microwave furnace that has wide applications in many fields. Microwave furnaces are used for sintering, polymer curing, sterilization and decontamination, and in other materials processing work. Ordinarily, the furnaces use microwaves with a fixed frequency. But materials differ in energy absorption characteristics, and a large portion of the heating power may be wasted if it is not efficiently absorbed by the material. Furthermore, the frequencies act in a way that is similar to a vibrating guitar string: the oscillations in the middle of the string are more pronounced than the movements at either end. With microwaves, these fluctuations cause the furnaces to have "hot" and "cold" spots, an undesirable condition when sterilizing medical equipment, for example. In curing polymers, uneven heat distribution can warp or burn the material catastrophically or jeopardize the material's strength by producing an inconsistent structure.

The innovative component in the new furnace is the traveling-wave tube, a microwave amplifier normally used for transmitting pictures of the outer planets to Earth. The ORNL invention utilizes a high-power, multikilowatt tube whose previous use had been limited solely to electronic warfare. After the concept of a traveling wave was decided upon, ORNL began looking for a traveling-wave tube manufacturer. None of the well-known companies made a high-power tube capable of the sophisticated heat transfer needed. Finally, the research team learned of a small company, Microwave Laboratories, Inc. (now Lambda Technologies), in Raleigh, North Carolina, that made high-power tubes for radar jamming. After settling on what was needed to construct the proposed furnace, Lambda built a "supertube" while the team at ORNL engineered the rest of the furnace. When the new furnace was tested in October 1991, its performance was exceptional.

High-tech ceramics are sintered in variable-frequency microwave furnaces.

By using Lambda's traveling-wave tube and a signal generator to vary, or "sweep," the frequencies in the microwave furnace, researchers can create a uniform power environment within the furnace's cavity, eliminating hot and cold spots. Also, materials heated in the furnaces sometimes have "magic frequencies" at which they absorb optimum levels of energy. Using Lambda's tube, researchers can monitor the sintering process and pinpoint those frequencies. Once they know that the sample is absorbing most or all of the energy, they can maintain the frequency while increasing the power, enhancing the sintering capabilities of the furnace.

ORNL has transferred and licensed the technology to Lambda, which now is manufacturing complete units, including the power supply, tube, and furnace. The private manufacturer has encountered a broad interest in the new technology from universities and the medical and scientific community. ORNL and Lambda recently signed a CRADA to further develop this technology. Both organizations benefit from the agreement. The variable-frequency furnace is a one-of-a-kind technology whose applications are so widespread that they are nearly impossible to foresee, and Lambda has a whole new line of business that could greatly expand the company's markets.

efforts in bioprocessing and the expanding role that bioprocessing will play in future industrial applications. The center's primary missions are to coordinate ORNL's multidisciplinary bioprocessing efforts, establish and maintain contact with external funding sources, identify and expand opportunities for interaction with other national laboratories, administer the Bioprocessing Research User Facility, and encourage technology transfer. Successes have included the establishment of the Interlaboratory Bioprocessing Consortium, which is currently active in the Alternative Feedstock Program. This con-

FLUIDIZED-BED BIOREACTOR ECONOMICS LOOK GOOD

ORNL arranged for Fluor Daniel Company to perform an economic analysis of the fluidized-bed bioreactor (FBR) process. The FBR is an ORNL development that operates continuously to produce chemicals for fuel and industrial use and in some configurations separates the desired chemicals from the production by-products. The FBR can use sugars from renewable feedstocks such as plant materials and wastepaper, displacing petroleum used for chemicals production.

The specific application studied by Fluor Daniel was an FBR for producing ethanol from cornstarch. The company looked at the economics of retrofitting an existing plant as well as new plant construction. Results showed that the FBR technology can save money, even in an existing plant. Savings of over \$0.02 per gallon of ethanol would accrue in a retrofit installation. Over \$0.06 per gallon savings would be realized in a new plant built around FBRs. The savings come from several sources:

- reduced downtime: the FBR operates continuously, unlike conventional batch processing;
- lower capital cost: equipment costs for the FBR process are at least 50% lower than conventional fermentation equipment costs; and
- reduced operating costs: feedstock is utilized more efficiently.

In a related study, an FBR is being used to produce lactic acid. Industry uses 30 million pounds of lactic acid per year in the production of foods and plastics. The FBR uses in situ separation by adsorption to remove the inhibitory lactic acid and shows a fourfold increase in volumetric productivity over reported values for conventional batch processing methods. Discussions are being held with industry on cooperative large-scale trials of the technology.

At ORNL's Bioprocessing R&D Center, researchers are exploring less-polluting ways to convert renewable feedstocks such as cornstarch and wastepaper to chemicals and fuels.

sortium has a memorandum of understanding to allow development of joint intellectual property between the member national laboratories.

Thermal Sciences Research. Studies in the thermal sciences have the goal of establishing and expanding the knowledge base that will support efficient energy conversion and utilization in industry. Research on heat transfer processes resulted in an ORNL invention, the recuperative liquid overfeeding heat exchanger, used in the automobile air conditioner described previously. Further refinement and optimization of the heat exchanger technology is being pursued in cooperation with DuPont. Technology licensing discussions have been initiated.

The thermal sciences group also completed numerical performance analyses of a magnetic refrigeration cycle. The technology base developed in the project supported the successful fabrication and testing of a prototype magnetic refrigerator by Astronautics Corporation of America. Magnetic refrigeration may be especially useful in large-scale gas liquifaction and cooling superconducting magnets.

Carl Zimm of Astronautics Corporation of America and Richard Murphy of ORNL with a magnetic refrigerator designed, constructed, and operated as part of an industry/national laboratory cooperative effort.

Thermal sciences research provides technology support to pulp and paper processes. ORNL is working with Bowater, Inc., Ahlstrom, and the Georgia Institute of Technology in investigating the thermal characteristics of the evaporative concentration of black liquors, which is a critical technology in the pulping process for the pulp and paper industry. Several sets of bench-scale falling-film evaporator modules similar to the ones installed at Bowater were fabricated by Ahlstrom for testing and analysis by the ORNL/Georgia Tech research team. Black liquors of various concentrations are being supplied by Bowater for the experiments. This activity is intended as an initial step in developing an energy-efficient, cost-effective black-liquor process for optimal process operations.

In support of the advanced impulse drying process being developed by the Institute of Paper Science and Technology and equipment manufacturers, ORNL is devising water-sensing techniques to further quantify the thermal dewatering efficiency of paper drying processes. In situ water-sensing devices will be tested in a controlled environment in the laboratory, and the prototypes will be field-tested in a pilot drying process for performance validation and technology demonstration.

Alternative Feedstocks for Chemicals Production. A project on alternative feedstocks for the chemical and petroleum refining industries is part of a cooperative initiative with participation by ORNL, Idaho National Engineering Laboratory, National Renewable Energy Laboratory, Pacific North-

west Laboratories, and Argonne National Laboratory. More than 90% of the basic feedstocks utilized for the production of nonenergy products by the U.S. chemical and petroleum refining industries originate from crude oil and natural gas. This project involves the displacement of petroleum by environmentally acceptable, renewable feedstocks; the potential energy impact is the displacement of about 1 quad of petroleum and natural gas by the year 2030. Renewable feedstocks can be starchy materials (typically corn and other grains); or lignocellulosics (woody materials such as wastepaper or woody biomass).

The first target is the production of organic acids, in particular, succinic acid, an intermediate product. The near-term goal is to demonstrate an economically competitive process for producing 1,4-butanediol from biologically produced succinic acid without production of gypsum as a by-product. ORNL is providing expertise in advanced bioreactors, adsorptive separations, and team leadership for the project. The Michigan Biotechnology Institute is collaborating with the multi-Laboratory team. ORNL has confirmed the literature fermentation data and is working to optimize the yield and rate. The initial economics are attractive; however, the current bioprocess must be demonstrated and improved before it can compete with the petrochemical process. Longer-term R&D are under way to incorporate more advanced technologies such as microbial immobilization to further reduce the costs. Integrated demonstration of this process is planned by a future industrial partner.

Pulp and Paper Processes. ORNL scientists are working on a variety of projects aimed at improving the energy efficiency of the pulp and paper industry. These include work on black liquor gasification (described under “Thermal Sciences Research,” paper drying, and fiber separation. One of these projects is described in the highlight “New Method for De-Inking Waste Newspaper.”

ORNL is poised to assist with the newly created Forest Products Program entitled Agenda 2020. This program is a voluntary collaborative effort between the forest products industry and DOE to provide the framework for identifying appropriate areas for joint research, development and technology demonstration in forests, wood, pulp, and paper. The result will be a research partnership between DOE and industry for demonstration, evaluation, and acceleration of new technologies and scientific insights that address several cross-cutting national needs:

- to advance the global competitiveness of the forest products industry by building technological leadership in the face of substantially increased R&D subsidies in major competitor nations in recent decades;
- to continue improving the sustainability of the forest resource, its multiple uses and its essential position as an available, stable, low-cost raw materials base to the industry;
- to be able to meet demanding requirements without increases in capital expenditures, operating costs, and energy consumption;
- to continue the significant progress in energy self-sufficiency and to take full advantage of available by-product biomass as a fuel source; and
- to increase further the economic viability and use of recycled wood and paper.

NEW METHOD FOR DE-INKING WASTE NEWSPAPER

The bioreactor used for the separation of uninked from inked fibers in old newspaper. Research findings show that the fibers can be separated based on fiber length distribution and strength. The uninked fibers represent high-quality secondary fibers that could be used as a partial substitute for chemical pulp, which currently sells for about \$400 per ton. The inked fibers could be de-inked, or could be used as is, e.g., for insulation or packing material.

ORNL has developed an environmentally friendly, energy-saving technology for removing ink from waste newspapers to make recycled paper products. The new biocatalytic technique uses the enzyme cellulase to treat the cellulose fibers that make up more than half of waste paper. Cellulase can completely break down cellulose into glucose sugar. However, under certain conditions discovered by the researchers, the action of cellulase results only in the separation of de-inked pulp fibers from inked fibers, with little cellulose breakdown.

The apparatus used for the process is simple. It consists of two cylindrical glass containers, or bioreactors, connected by a tube through which water circulates. In each container is a cylindrical basket made of 20-mesh plastic canvas, commonly used for needlepoint.

Waste paper and cellulase are mixed in the basket in the first bioreactor. The mixing of the cellulase with the waste paper separates its large and small pulp fibers and triggers the release of ink from the paper surface. The released ink tends to stick to the small pulp fibers. As water flows between the two containers, the small inked fibers pass through the pores of the plastic basket and end up in the other bioreactor outside its basket. The larger ink-free pulp fibers remain inside the basket of the first container because they are too large to pass through the basket pores.

The enzyme, or biocatalyst, technology has three advantages over the traditional de-inking technology. First, it works on old newspapers that

use water-based ink as well as oil-based ink, without releasing ink to the environment. Second, because it requires no de-inking chemicals, it uses much less energy than traditional methods. If the technique were used on the 8 million tons of newspapers collected annually for recycle, 0.018 quads of energy, or 13 million barrels of oil per year, could be saved. Third, the ORNL technology is environmentally friendly because cellulase is an enzyme produced naturally by a fungus. Traditional de-inking technologies use potentially harmful chemicals such as caustic sodium hydroxide, sodium silicate, and hydrogen peroxide.

Several paper companies have shown interest in the ORNL technique. Discussions on technology development needs are ongoing with some of these companies.

These are the critical long-range needs that must be met in order to take continuing advantage of the unique benefits of wood-based products, exemplified by their low embodied energy and renewability as a raw material. These inherent advantages stem from the nature of the forest resource, which has multiple uses as an ecosystem resource, including watershed stabilization, preservation of groundwater quality and habitat diversity, soil conservation, and contributions to the atmospheric carbon dioxide balance.

WASTE REDUCTION TECHNOLOGIES

Advanced Industrial Heat Exchangers. A continuing project at ORNL provides materials technology support to DOE and its contractors for development of advanced industrial heat exchangers. Support to Stone and Webster Engineering Corporation is being provided through studies of corrosion resistance in ceramic heat exchanger tubes in a steam-methane reformer atmosphere. ORNL is assisting Solar Turbines, Inc., through evaluation of ceramics for use in heat exchangers in an industrial waste incinerator. ORNL performs similar evaluations for Babcock & Wilcox; Babcock & Wilcox exposes ceramic and ceramic composite tubes to a hazardous waste incinerator atmosphere, and sections of the tubes are examined at ORNL after exposure.

Industrial Heat Pumps. An ORNL project on industrial heat pumps is developing "high-lift" heat pumps that use industrial reject heat to produce in-plant, utility-grade process heating and cooling (refrigeration). High-lift heat pumps offer larger temperature lifts and can deliver process heat at temperatures up to about 260°C (500°F) and process cooling down to about -50°C (-58°F). Proof-of-concept experiments will be completed this year. Bench-scale development of promising concepts will then begin, with field testing of prototype units to start in 1997. This work builds upon successful commercialization of two earlier concepts: the Brayton cycle solvent recovery heat pump and the ammonia sorber for evacuating refrigeration systems for maintenance.

Advanced Turbine Systems. In FY 1993, DOE initiated a program to develop ultrahigh-efficiency, clean, cost-competitive gas turbines for utility and industrial markets. ORNL is coordinating the materials and manufacturing element of the initiative with the goal of developing materials and manufacturing techniques to withstand turbine inlet temperatures of over 1400°C. The specific performance targets that are supported by the materials element include a system efficiency that will exceed 60% for large-scale utility turbine systems and a 15% decrease in power costs as well as reduced emissions for industrial turbines.

The research program is closely coordinated with industrial and utility turbine users and manufacturers to ensure that the critical needs and issues for all stakeholders are addressed. A technical plan defined areas of interest for project solicitations to be issued in 1995. The primary technical issues to be addressed are coatings and process development, turbine airfoil development, ceramic development, single crystal airfoil manufacturing technology, and materials characterization. Long-term creep and stress rupture tests of ceramics are under way. A future thrust of the Advanced Turbine Systems program will involve increased utilization of biomass fuels for cogeneration and dispersed electricity production.

Energy-Efficient Motors and Drive Systems. Motor-driven systems are the backbone of U.S. industrial operations. More than 40 million motor systems are currently powering industrial processes for applications such as fluid handling and movement, and material processing and fabrication. These systems account for more than 70% of all electricity used by the industrial sector. Improvements in the

efficiency of these electric motor systems can translate directly into enhanced productivity, competitiveness, and environmental performance. To promote the use of energy-efficient electric motors systems, DOE/OIT has developed the Motor Challenge Program (see highlight). ORNL provides technology development support to this DOE initiative by developing validation and measurement tools and techniques and by compiling a database on the performance of existing motors.

THE MOTOR CHALLENGE

Launched in 1993, the Motor Challenge is a voluntary DOE-sponsored initiative to foster the development and adoption of more efficient electric motor systems. In partnership with U.S. industry, motor drive manufacturers and distributors, and other key participants, DOE is providing the critical information and tools that companies need to make sound, informed decisions on incorporating energy-efficient electric motors and related equipment into their production processes.

The Motor Challenge involves partnerships, showcase demonstrations, and market transformation. Partnerships are the cornerstone of the program. Stakeholders are involved in all program activities, from program design and implementation to evaluation. To date, more than 230 organizations have joined the Motor Challenge as partners. Market transformation strategies are focusing on leveraging the substantial market position of large motor system

users, such as electric utilities, states, and the federal government, to create a demand-pull for motor systems equipment with improved system-level efficiency.

ORNL's involvement in the Motor Challenge has primarily focused on the showcase demonstrations. The Laboratory helped DOE with the design and implementation of a contest that will result in 25 pilot showcase demonstrations of energy-efficient electrical motor systems. In addition, ORNL is developing tools and protocols to assist in finding efficiency opportunities and validating the energy savings achieved. These tools, and other forms of technical assistance, will be provided to the 25 contest winners. Results from the showcase demonstrations will be used to identify R&D needs in electric motor systems. It is estimated that the Motor Challenge will reduce the emissions levels projected for the year 2000 by almost 10 million metric tons of carbon equivalent.

Cellulosic Waste Minimization and Bioconversion. A project on cellulose waste minimization and bioconversion consists of modification of biocatalysts to allow economic utilization of wastepaper in fuel and chemical production processes. Wastepaper is an example of lignocellulose, one of the most abundant compounds on earth. Other examples are municipal wastes, agricultural residues, and grasses. The main objective of this collaborative project between ORNL and Eastman Chemical Company is to increase the process efficiency for the manufacture of cellulose esters.

High-quality alpha-cellulose (cotton linters) costs about \$1,000 per metric ton. Considerable economic savings to industry could be realized if waste cellulosic materials could substitute, at least partly, for cotton linters. In order to generate high-quality cellulose suitable for esterification, R&D is needed to develop the technology for the activation and recycle of waste cellulose. Tasks include development of biocatalysts that have enhanced activity on lignocellulosic feedstocks for fermentation sugar (e.g., for ethanol production) and that can degrade waste cellulose ethers and esters for recycle into cellulose fibers.

GET A "LIFT" FROM INDUSTRIAL HEAT PUMPS

DOE has estimated that efficiency improvements in industrial heat pumps can save up to 1,500 trillion Btu (or the equivalent of \$4 billion at current energy prices) by the year 2010. To realize the full savings, DOE is promoting an integrated approach to providing process heating and cooling at industrial sites. In this approach, waste heat from one or many processes is fed to a heat pump that can produce heating or cooling for other process needs, including the site or plant central utility system. This requires a "high-lift" heat pump. Heat pumps take in heat at a low temperature and deliver it at a higher temperature; current practice can "lift" heat from about 50°F to about 300°F. "High-lift" chemi-

cal heat pumps offer a greater temperature range, up to about 500°F.

Working with ORNL, Energy Concepts Company has developed and patented a fluid called Alktrate™ that consists of alkali metal nitrate salts dissolved in water. The low corrosivity of this fluid allows heat pumps to be constructed out of standard materials, producing moderately priced chemical heat pump systems. Another company, Rocky Research, is developing a solid/vapor working medium using ammoniated complex salt compounds. These are excellent working media candidates because they can absorb large mass ratios of refrigerant, can potentially be stable up to 600°F, and are generally nontoxic and inexpensive.

Using heat pumps to recycle waste heat could save 1.5 quads of fuel normally burned in boilers and fired process heaters, saving up to \$4 billion by the year 2010 (at current energy prices).

UTILITY TECHNOLOGIES

Electricity is the fuel of the information era. Just as coal powered the industrial revolution, electricity is key to powering information. Related to this notion is the fact that, during the past several decades, electricity's share of U.S. primary energy use has been steadily increasing, rising to about 37% of the total in 1993.

Given the likelihood of continued growth in demand for electric power well into the foreseeable future, the nation is faced with the challenge of ensuring that electricity is delivered efficiently to end users and that cost-effective renewable resource options are available. In addition to improving the efficiency of power conversion at electric utility plants, significant opportunities exist to reduce the transmission and distribution losses that are estimated to be 9% of gross generation of electricity by utilities.

ORNL provides field management (including assistance in engineering and analytical studies and technical support for planning and decision-making) for three programs within DOE's Office of Utility Technologies. These programs deal with power transmission and distribution technologies, high-temperature superconductivity, and electric and magnetic field effects. ORNL also conducts research and provides technical assistance to the Integrated Resource Planning Program and conducts research on hydrogen production and fuels infrastructure and thermal energy storage. Recently, ORNL initiated a study of district heating, cooling, and cogeneration to determine their energy, economic, and environmental benefits in accordance with the Energy Policy Act of 1992.

POWER SYSTEMS TECHNOLOGY

ORNL conducts research on a wide range of topics important to the nation's ability to deliver electric power. Working with the DOE power-marketing agencies, several utilities, the Electric Power Research Institute, and other interested parties, ORNL seeks to improve electric system capacity, flexibility, and efficiency while maintaining high system reliability. The Power Systems Technology Program includes development of real-time control to allow power systems to be operated closer to thermal limits; high-capacity transmission options; and technologies designed to improve understanding of transient phenomena and dielectric materials characteristics. The program also conducts research on the possible health effects of magnetic and electric fields. Milestones for FY 1996 include a demonstration of the feasibility of controlled turn-off, high-voltage direct-current converters.

High-Capacity Transmission Options. ORNL's research on high-capacity transmission options has two thrusts: improving the feasibility of high-voltage direct current transmission and demonstrating high-phase-order alternating current transmission lines. The high-voltage direct current program is developing advanced, low-cost converter configurations, investigating alternatives to semiconductors as switching devices, and assessing silicon carbide as a basis for a new generation of high-voltage, high-current solid-state switches.

The High-Phase-Order Demonstration Project was initiated in 1992. It is being conducted by New York State Electric & Gas (NYSE&G) Corporation in Binghamton, New York, with ORNL as the technical monitor. An existing 1.5-mile double-circuit three-phase line operating at 115-kilovolt line-to-line has been converted to six-phase operating at 161-kilovolt line-to-line. A 73% increase in line

capacity is technically possible when converting from three-phase to six-phase operation. The detailed line design and construction were completed between May 1990 and July 1992.

During the first week of July 1992, the six-phase line was energized, becoming the world's first commercially operated six-phase transmission line. The \$11.4 million demonstration is being funded by an industry consortium consisting of NYSEG, Empire State Electric Energy Research Corporation, New York State Energy Research and Development Authority, New York State Energy Office, the Electric Power Research Institute, and DOE.

ORNL is the technical monitor for the world's first commercially operated six-phase transmission line, in Binghamton, New York, for the New York State Electric & Gas Corporation.

Electric and Magnetic Fields. Public concern about possible health effects from power frequency electric and magnetic fields (EMFs) has grown dramatically. Although research laboratories have issued numerous reports of EMF biological effects, the reliability of the results are often questioned because few have been replicated at other laboratories. Accordingly, Congress mandated the formation of the National Electromagnetic Field Research and Public Information Dissemination (RAPID) Program as part of the 1992 Energy Policy Act. This multiagency effort is being led by the National Institute of Environmental Health Sciences (NIEHS) and DOE, which has designated ORNL as its lead laboratory for the program.

The program includes a wide range of research and communications activities designed to provide answers to health questions in the 5-year program lifetime. DOE and NIEHS will address the issue of research replicability with a cooperative, multilaboratory replication program designed to carefully repeat key experiments reported in the literature. The four national replication sites will be the Food and Drug Administration (FDA) in Rockville, Maryland; the National Institute of Occupational Safety and Health (NIOSH) in Cincinnati; the Pacific Northwest Laboratory in Richland, Washington; and ORNL.

The FDA and NIOSH exposure systems are already in place, and the ORNL system will begin operating this spring. Four purposes for the systems have been identified:

- Each laboratory will attempt to replicate important reported EMF bioeffects.

- If any of the replications succeed, simultaneous replications will be attempted at all four laboratories.
- The exposure systems will be made available as user facilities to researchers working in this field.
- Each laboratory will pursue promising research directions in accordance with their in-house expertise and interests.

An ORNL scientist serves on the steering committee for the replication activities, and several researchers at the Laboratory have experiments planned to begin as soon as the systems are installed.

SUPERCONDUCTIVITY PROGRAM FOR ELECTRIC POWER

The goal of the Superconductivity Program is to develop the technology base needed for U.S. industry to proceed to commercial development of electric power applications of high-temperature superconductors. The three major elements of the program are wire development, electric power applications development, and the Superconductivity Partnership Initiative. Superconductivity collaborative agreements are the principal mechanism used to enable industry participation. Thirty-three agreements have been signed to date; 20 of these have been successfully completed, and 13 are currently active. These agreements have resulted in more than \$15.5 million in program cost sharing from industry, an amount that exceeds DOE's funding for the Superconductivity Program at ORNL. Twenty-six inventions have been disclosed since the program began, and many more are anticipated.

Amit Goyal inserts a sample of a high-temperature superconducting material into the cryostat used to measure the properties of a superconducting wire sample in the liquid-helium to liquid-nitrogen temperature range. He is working on cooperative agreements with American Superconductor, Intermagnetics General, and General Electric.

Highlights of the program's technical accomplishments include the following:

- ORNL completed the first phase of the program's most comprehensive study of the mechanism for current flow in high-temperature superconductors. In two of the three classes of materials studied, reduced weak-link behavior was ascribed to some degree of biaxial alignment between grains, either on a macroscopic scale (tens of

millimeters) or on a microscopic scale (less than 1 millimeter). ORNL's discovery of a "local order of grains," resulting in long-range percolative current paths through a network of small-angle grain boundaries at colony intersections, provides a working model for the microstructure of practical polycrystalline wires.

- In April 1993, Superconductive Components, Inc., signed an agreement to license ORNL's superconducting aerosol powder production technology. As a result of that license, Superconductive Components initiated the commercial sale of superconducting aerosol powders in FY 1994.
- In collaboration with General Electric, ORNL completed a conceptual design report for a partial helical stator winding for a 100-megavolt-ampere superconducting generator. This phase of the Superconductivity Partnership Initiative project has been deemed to be of substantial commercial interest to General Electric.
- At the annual Peer Review of Projects for the Superconductivity Program for Electric Power Systems, an ORNL project, "AC Applications of High-Temperature Superconductor Wires and Coils," was highly acclaimed for its technology transfer activities and received the highest overall score in that category. In addition to achieving excellent progress in wire and magnet development, this project was cited by the review committee as the "best example of industry/national laboratory collaboration in the entire program." Working with American Superconductor Corporation, the project team determined the lower limit for the stability margin of high-temperature superconductor wire and developed new twisted multifilamentary wires for alternating current applications.

1-T high-temperature superconductor magnet made by the American Superconductor Corporation. The screw heads on the top plate of the magnet are the terminations of the voltage taps and other instrumentation.

The program has also produced several teaching modules aimed at translating superconductivity concepts for high school and middle school students. During FY 1994, a physics teacher from Largo, Florida, and an ORNL staff member completed *A Teacher's Guide for Superconductivity for High School Students*. This effort was supported by both the Superconductivity Program and DOE's Office of Science Education. The guide was reviewed by local schools and science museums and is now available from the National Technical Information Service. In a related activity, ORNL produced *A Teacher's Guide to Cryogenics and Superconductivity for Middle School Students*. The guide includes a videotape and instructions for obtaining laboratory demonstration materials.

HYDROGEN PRODUCTION AND FUELS INFRASTRUCTURE

Hydrogen as a fuel has three times the energy content of gasoline, on an equivalent mass basis. When used as a fuel in fuel-cell-powered vehicles, it can provide two to three times the energy conversion efficiency of conventional gasoline-fueled, internal combustion engine vehicles. Hydrogen fuel cell vehicles operate quietly and produce no emissions other than water. They are environmentally benign and can be considered to be true "zero emission vehicles." In addition, hydrogen, unlike fossil-derived fuels, has a limitless resource base, including, for example, water, biomass, and even fossil fuels.

Two new projects for DOE's Office of Energy Management are helping to advance the feasibility of hydrogen as a vehicle fuel. The first project investigates photosynthetic water splitting by algae as a renewable source of elemental hydrogen. A photobiological reactor to produce hydrogen in subambient atmospheres is being designed, and discussions are under way on other studies of hydrogen as a replacement for fossil fuels.

An exciting discovery has been made in the course of research on photobiological reactors. An alga was observed to perform photosynthesis with only Photosystem II, whereas photosynthesis is generally assumed to require Photosystem I and Photosystem II. This doubles the theoretical efficiency of hydrogen production. Photobiological reactors are algal systems that are being studied for carbon dioxide fixation and recycling, hydrogen production, and methane removal.

In the second project, DOE has tasked ORNL with designing conceptual hydrogen fuel dispensing stations (similar to present-day gasoline stations) and assessing the infrastructure requirements for these facilities. This work will perform technical and economic assessments to develop the infrastructure requirements that will facilitate the introduction of hydrogen as an environmentally desirable replacement for present-day petroleum-derived transportation fuels.

The work includes the development of design requirements for a conceptual hydrogen fuel dispensing facility similar to gasoline-dispensing stations. This facility will be designed as a stand-alone plant to produce hydrogen from natural gas using conventional steam reforming and water gas shift processes. Other hydrogen production processes (such as partial oxidation of hydrocarbons and water electrolysis) will be reviewed to determine their suitability for manufacturing the hydrogen for the stand-alone dispensing station. The study also will include an assessment of the environmental permitting and other regulatory requirements likely to be imposed on building and operating a hydrogen-dispensing station for fueling light-duty transportation vehicles.

Nuclear gene deletion mutant alga observed utilizing only Photosystem II in photoproduction of hydrogen.

The assessment includes the following tasks:

- a review of industrial hydrogen production processes;
- development of the design basis for a typical hydrogen dispensing station for light-duty transportation vehicles;
- development of the process design and cost estimates for a grassroots hydrogen-dispensing facility using the steam reforming and water gas shift processes;
- evaluation of the regulatory and other permitting requirements for the conceptual stand-alone hydrogen dispensing station;
- preparation of sensitivity analysis on the conceptual dispensing station design; and
- preparation of the technology assessment report on the hydrogen-dispensing station study.

The study will produce a technology assessment report (due June 1995) that includes a review of the feasible technologies for producing fuel hydrogen from fossil fuels, process design, and cost estimates for a conceptual hydrogen fuel dispensing station, and an evaluation of the potential regulatory permitting requirements for building and operating such a station.

The technology assessment report is expected to be used as the basis for evaluating a hydrogen dispensing station demonstration facility. At present, this facility is likely to be located either in Chattanooga, Tennessee (to power a fuel-cell bus for the 1996 Summer Olympics in Atlanta, Georgia) or in the Los Angeles basin in southern California. The demonstration facility is expected to be a collaborative project funded by industry (e.g., the Electric Transportation Vehicle Institute) and state and federal agencies (e.g., the California Energy Commission, DOE, and the U.S. Environmental Protection Agency).

RENEWABLE ENERGY CONVERSION

ORNL provides technical and analytical support to the DOE Office of Renewable Energy Conversion in the areas of geothermal energy, biomass energy, hydroelectric power, and other renewables. ORNL is conducting a study of chemical reactions in geothermal systems for DOE Headquarters and the DOE Idaho Operations Office. Another renewable energy project provides support to the California Energy Commission in an assessment of geothermal heat pump performance and economics. ORNL also recently assisted with the preparation of an environmental impact statement and related work for the Hawaii Geothermal Project. On May 17, the DOE published a *Federal Register* notice withdrawing its Notice of Intent to prepare an environmental impact statement. ORNL's remaining work consists of archiving the data and bringing the project to an orderly close.

ORNL also supports DOE's new Advanced Hydropower Turbine Initiative and has conducted a study of ways to improve hydropower production at existing facilities. ORNL is assisting DOE in selecting engineering contractors to develop a more environmentally friendly hydropower turbine.

ENVIRONMENTAL IMPACTS

Since 1978, ORNL has been the lead environmental research and analysis facility for DOE's hydropower program. The staff conducts studies to help promote environmentally sound hydropower development, providing guidance to regulators, resource managers, and developers on solving environmental problems. A major study of environmental mitigation practices by the hydropower industry is under way. One volume of the report, covering mechanisms used to pass fish upstream and downstream past dams, was completed in 1994. Another volume deals with correcting effects of dams on dissolved oxygen in water released from turbines. The Laboratory currently is providing environmental support to DOE's new Advanced Hydropower Turbine Initiative, which plans to develop turbine designs that are less likely to damage fish, especially valuable young salmon, passing through them.

A second role is to provide environmental impact analyses for DOE and related programs and agencies. ORNL supports the Federal Energy Regulatory Commission in preparing environmental impact statements and conducting environmental assessments on hydropower. ORNL staff have evaluated the environmental effects of small hydropower development and relicensing of existing projects in northwest Washington State and the Central Valley of California. ORNL also recently assisted with the preparation of an environmental impact assessment of geothermal development in Hawaii.

Recently, a study was completed for the DOE Policy and Planning Office in which administrative and regulatory options were recommended that could streamline the current licensing process. The results of this study were provided to Vice President Gore, to assist in the "reinventing government" initiative for making the government more efficient. There is much room for improvement in hydropower licensing because it is one of the most overregulated of energy industries.

ORNL conducts research on population-level effects on fish for DOE, the Electric Power Research Institute, and the Pacific Gas and Electric Company under CRADAs. At issue is a better understanding of the basic mechanisms by which fish populations respond to the problems caused by dams, such as poorer water quality, low stream flow, and mortality during passage upstream and downstream past dams. The work is designed to help examine the long-term effectiveness of environmental mitigation measures.

The Grand Coulee Dam in Washington was one of the first large federal hydroelectric projects in the United States. Both federal and nonfederal dams in the Pacific Northwest have had an adverse impact on salmon populations. ORNL has evaluated the environmental and socioeconomic impacts of nonfederal dams throughout the United States for the Federal Energy Regulatory Commission.

THERMAL ENERGY STORAGE

For 14 years, ORNL has conducted a program to develop thermal energy storage (TES) technologies for industries and buildings. The current program consists of cost-shared subcontracts for development of wallboard with enhanced heat capacity, and development of a low-temperature TES system for off-peak refrigeration.

ELECTRIC INDUSTRY POLICY STUDIES

For 15 years, ORNL staff have conducted research, analysis, and outreach activities dealing with the design and evaluation of demand-side management (DSM) programs, electric-utility resource planning, and the impacts of the increasingly competitive power market (see highlight on stranded commitments). This work has contributed significantly to the expansion of DSM programs as a means of meeting electric utility resource requirements.

Since the early 1990s, considerable effort has focused on integrating and synthesizing the expertise of several DOE laboratories, so that the total DOE program of research on electric industry issues profits from their complementary strengths and avoids duplication. The primary laboratories involved in this coordinated effort have been Lawrence Berkeley Laboratory, Pacific Northwest Laboratory, the National Renewable Energy Laboratory, and ORNL.

Another feature of ORNL's program has been its close working relationships with electric industry stakeholders, as is illustrated by the numerous off-site assignments held by staff members, who have worked for extended periods of time at state energy offices, major electric utilities, and environmental research groups. Most recently, Larry Hill has been a Visiting Fellow at the National Conference of State Legislatures in Denver, Colorado, where he is collaborating with state legislators and their staffs on electric-power restructuring legislation and policy.

In 1979, as utilities started to offer energy audits to their residential customers in response to the 1978 National Energy Act, ORNL developed and implemented methods to evaluate the impacts of these audits. Rather than relying on engineering algorithms to estimate energy savings, ORNL focused on the *measurement* of savings via metering, end-use monitoring, and the analysis of utility bills. Today, many electric and gas utilities, as well as state energy offices and public utility commissions, use the methods pioneered at ORNL to evaluate the cost-effectiveness of DSM programs. Much of this research and experience was codified in ORNL's 1991 *Handbook of Evaluation of Utility DSM Programs*.

Building on its experience with DSM-program planning and evaluation, ORNL expanded its work to encompass utility planning for all resources to meet customer energy-service needs. Work on what came to be called integrated resource planning (IRP) began in 1985. Since then, ORNL staff have developed, applied, and documented methods to do such planning in a way that treats DSM and supply resources on a consistent basis. Numerous utilities and state regulatory commissions have used ORNL publications in the design and review of their IRP methods and processes.

ORNL continues to develop planning methods, evaluation tools and handbooks, and financial models to assist with the design and assessment of DSM programs. Every year, ORNL staff analyze the

Errors in the statistical-recoupling estimates of total electricity use for 1990, 1991, and 1992 for five utilities. (The percentage changes in electricity price would be 50 to 75% of the percentage change in use shown here.)

DSM data reported by electric utilities to the Energy Information Administration. Staff have developed and analyzed various mechanisms that affect utility shareholders when the utility runs such programs. The more electricity a utility sells between rate cases, the more money it makes for its shareholders. The reverse is also true. ORNL developed a new method, statistical recoupling, to address this problem. Statistical recoupling decouples electric revenue from sales and

then recouples revenues to the determinants of electricity sales. These determinants typically include local weather conditions (heating and cooling degree days), economic conditions (personal income or industrial production), electricity price, and perhaps a few other factors. A test of this approach with data from five utilities gave surprisingly good results (see graph). They show that implementation of statistical recoupling would remove the disincentive in current regulations to utility DSM programs and would cause only minor year-to-year changes in electricity prices.

In addition to publishing an ORNL report and several journal articles on this new method, ORNL staff have briefed utilities and regulatory commissions in Florida, New York, Colorado, and Utah on the method. In response to one of these briefings, the chairman of the New York Public Service Commission, noted that the "exchange was extremely informative and helpful to our work. . . . Over the years, the New York State Public Service Commission has benefited from help provided by the Oak Ridge, Lawrence Berkeley, and National Renewable Energy Laboratories."

WHOSE COMMITMENTS WILL BE STRANDED BY UTILITY REORGANIZATION?

New technologies, low natural gas prices, and federal and state utility regulations are restructuring the electricity industry. Yesterday's vertically integrated utility with a retail monopoly franchise may be a very different organization in a few years. Conferences and regulatory commission hearings are dominated by debates over the extent and form of utility deintegration, wholesale competition, and retail wheeling.

A key obstacle to restructuring the electricity industry is stranded commitments. Past investments, power-purchase contracts, and public-policy-driven programs that made sense in an era of cost-of-service regulation may not be cost-effective in a competitive power market. Regulators, utilities, and other parties face tough decisions concerning the mitigation and allocation of these stranded commitments.

ORNL developed a method to calculate the amount of stranded commitments facing U.S. investor-owned electric utilities. These calculations were based on a variety of assumptions about

- the fraction of utility sales that is at risk with respect to competition,
- the market price of electric generation, and
- the number of years during which the utility would lose money because of differences between its embedded cost of production and the market price.

Estimates of stranded commitment can vary widely depending on the assumptions used; losses could range from less than 40% to more than 50% of utility equity. Lower estimated losses will result if competition occurs for industrial customers only, and higher estimated losses will result if competition occurs for all retail customers. In both cases, losses are concentrated in a few states, including California, New York, Ohio, and Pennsylvania. Utilities in Kentucky, Missouri, Montana, Virginia, and Washington, on the other hand, face little threat of stranded commitments.

In one scenario, the utilities in 18 states face losses exceeding 50% of their shareholder equity as the result of stranded commitments.

CROSS-CUTTING PROGRAMS

ORNL manages and provides assistance to a variety of cross-cutting programs that promote the adoption of available but underutilized efficiency and renewable energy technologies. Many of these activities are supported by DOE's Office of Technical and Financial Assistance (OTFA). OTFA promotes the rapid domestic deployment of energy technologies by providing financial aid, training, and technical assistance primarily through a network of regional, state, and local intermediaries. OTFA also participates in international programs that support the development of export markets for energy technologies, including several that are coordinated by the International Energy Agency (IEA).

ORNL conducts program evaluations, provides technical assistance, and undertakes policy analysis to support these domestic and international programs. Similar activities are undertaken for other DOE offices and other organizations such as the Agency for International Development. A subset of ORNL's accomplishments in these these cross-cutting programs are described below in terms of support for national programs, support for IEA programs, and support for international initiatives.

SUPPORT FOR NATIONAL PROGRAMS

ORNL has had a long-term involvement in supporting two national programs operated by DOE/OTFA—the low-income Weatherization Assistance Program and the Energy-Related Inventions Program. The Laboratory also has periodically provided assistance to other OTFA programs, including the Regional Biomass Energy Program, the Efficiency and Renewable Energy Network, and the State Energy Conservation Program. Some of these activities are summarized below.

National Weatherization Evaluation. The low-income Weatherization Assistance Program is the nation's largest conservation program. The goals of the Program are to decrease national energy consumption and to reduce the impact of high fuel costs on low-income households, particularly those of the elderly and the handicapped. ORNL has assisted DOE by conducting an evaluation of the program's overall performance, field testing alternative packages of retrofit measures, evaluating individual retrofit measures for possible inclusion in the program, and developing energy audit tools to guide the selection of retrofit measures for individual dwellings. During 1994, ORNL completed a three-year, \$5 million evaluation of the Weatherization Assistance Program. Because the Program is implemented by more than 1,100 local agencies located across the country, the evaluation required an elaborate sampling design and an extensive amount of data.

Energy savings of DOE's Weatherization Assistance Program, by climate region.

The evaluation concluded that during the 1989–90 program year, the program saved 16.4 MBtu per weatherized dwelling, or 18% of the energy used for space heating. When summed over the 20-year lifetime of the weatherization measures and the 200,000 participants during 1989–90, these savings represent the equivalent of 12 million barrels of oil. In addition, the reduced energy consumption decreased carbon dioxide emissions by more than 4 million metric tons. A comparison of costs and benefits from a range of perspective, concluded that the program is a cost-effective government investment.

A variety of analytical techniques were used to identify the most effective weatherization measures and procedures as well as areas requiring programmatic improvements. For instance, high-density wall insulation and furnace replacements were found to produce high savings, whereas storm windows and weatherization in warm climates generally did not. As a result of the findings of this evaluation, DOE (with assistance from ORNL) is developing an initiative to improve the cost-effectiveness of weatherization in warm climates.

The value of this project to stakeholders is summarized by Dr. Laurence Kinney, President of Synertech Systems Corporation, in Syracuse, New York: “The National Evaluation has produced the first comprehensive analysis of the amount of energy saved by DOE’s low-income Weatherization Program. ORNL’s work has laid the foundation for making the Program even more cost-effective by identifying opportunities for improvement and by describing innovative local agency approaches that can be emulated by others.”

National Energy Audit. Another recent ORNL accomplishment sponsored primarily by OTFA is the development of the National Energy Audit (NEAT) (see highlight). Thirty state weatherization programs now use this public domain software. Its ability to produce enhanced savings over previous techniques for selecting weatherization measures has been well documented.

Energy-Related Inventions Program. For more than a decade, ORNL has been involved in quantifying the energy, economic, and environmental impacts of DOE’s Energy-Related Inventions Program (ERIP). ERIP was established in 1976 to facilitate the development of non-nuclear, energy-related inventions. It directs its resources to small business and independent inventors, providing them with technical assessments of their inventions, grants, and commercialization education.

For more than a decade, ORNL has traced the progress of a sample of inventors supported by ERIP. Its unparalleled database of longitudinal data on the information process has allowed ORNL to characterize the innovation process as it pertains to small business energy technologies and to recommend ways to improve the program.

The following bullets present the most recent indicators of program impacts. Comparisons between these indicators and the performance metrics of other programs and innovations suggest that ERIP has significantly enhanced the market success of its participants.

- **Market Entries:** At least 129 ERIP technologies commercialized, representing a 23% commercialization rate.
- **Sales:** \$763 million (in 1992 dollars) of sales generated by these 129 technologies through 1992.

ADVANCED AUDIT NOW USED NATIONWIDE TO SELECT RETROFIT MEASURES

Working with two DOE Programs (the Weatherization Assistance Program and the Existing Buildings Program), ORNL has developed an advanced energy audit for use by states and utilities for retrofitting single-family homes. The National Energy Audit (NEAT) uses a variety of data on the building and its heating and cooling systems to produce a prioritized list of cost-effective weatherization measures, customized for individual houses. NEAT considers both envelope and heating and cooling system needs, and produces estimated energy savings, savings-to-investment ratios, and a list of the quantities of materials necessary to complete weatherization. Another distinguishing feature is its use of billing histories to gauge the relative opportunities for savings and to reconcile engineering estimates of consumption and savings. NEAT is advanced, yet user-friendly.

The results of several field tests monitored by ORNL have documented that NEAT can result in the selection of more cost-effective energy retrofit measures, enabling greater energy savings for every dollar invested. It is estimated that the use of NEAT enables savings

Types of data analyzed by NEAT.

from DOE's low-income Weatherization Assistance Program to increase from 18% of the energy used for space heating to at least 25% of space heat energy use.

This year, NEAT will be used by approximately 500 local agencies in 30 states and will guide the retrofitting of more than 100,000 low-income dwellings. Based on the field tests, NEAT will save approximately \$56 million in energy costs over the lifetime of the retrofits completed this year, which far exceeds the \$2 million that DOE spent to develop the audit tool.

ORNL has provided NEAT and user training to numerous state agencies and utilities. ORNL will continue enhancing the audit and will extend its application to middle-income housing, small multifamily buildings, and rehabilitation projects. Improved methods for obtaining detailed electric energy use data in buildings are also being developed.

Several electric and gas utility companies have already adopted NEAT to assist with their demand-side management programs.

Results of two field tests of the National Energy Audit.

- **Licensing Revenues:** \$18.6 million (in 1992 dollars) for licensed sales of ERIP technologies through 1992.
- **Spinoffs:** An additional \$63 million in sales generated by 36 spinoff technologies.
- **Funds Raised:** \$2.01 raised by inventors after receipt of ERIP grant for every ERIP grant dollar.
- **Jobs:** 668 full-time-equivalent jobs directly supported by ERIP technologies in 1992.
- **Taxes:** \$2.7 million in ERIP-related individual income tax revenues returned to the U.S. Treasury in 1992.
- **Energy Savings:** \$531 million (in 1992 dollars) of energy expenditures saved by three ERIP technologies.
- **Environmental Benefits:** Carbon emissions reduced by almost 1 million metric tons, as the result of three ERIP technologies.

During FY 1993, ORNL designed and conducted an evaluation of ERIP that compared the progress of program participants and a matched group of program referrals. The goal was to isolate the effects of the program from the myriad other factors that influence the progress of inventors. The resulting report is one of the first published accounts of applying a quasi-experimental control group design to the evaluation of a technology innovation program. It underscored the value added by participation in DOE's Inventions Program.

The results of ORNL's evaluation of DOE's Energy-Related Inventions Program have been used to improve the operation of ERIP and to enhance other federal and state programs intended to foster small-business innovation.

SUPPORT FOR IEA PROGRAMS

Environmentally sound energy technologies represent a major international need and constitute one of the biggest emerging export opportunities for U.S. industry. In total, the world market for renewable energy technologies is estimated at \$150 billion annually. The market for energy efficiency goods and services is estimated to be \$84 billion annually. These markets offer numerous opportunities for the creation of new U.S. businesses and jobs. By participating in activities of the International Energy Agency (IEA), DOE is able to publicize the availability of U.S. technology solutions that might help both developing and developed countries meet their energy, economic, and environmental goals.

The IEA was created in 1974 within the framework of the Organization for Economic Cooperation and Development. It implements an international energy program of cooperation aimed at reducing the excessive dependence on oil among its 23 member countries, through energy conservation, development of alternative energy sources, and energy research and development. Activities are set up under Implementing Agreements which provide the legal mechanisms and management structure for collaboration. ORNL manages and supports the U.S. involvement in many of these implementing

agreements, either as executive committee members, national team leaders, or operating agents. Three of these activities are described below: the Greenhouse Gas Technology Information Exchange (GREENTIE), the Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), and the Heat Pump Program.

Greenhouse Gas Technology Information Exchange. GREENTIE was formed under the auspices of IEA in October of 1993. This new implementing agreement was created in response to concerns of IEA member nations about the global rise in temperature caused by man-made changes in the composition of the atmosphere, and their questions about appropriate remedial action. The GREENTIE objectives are to identify greenhouse gas mitigation technologies that have a potential for international deployment and to publicize the availability of these technology options to potential decision-makers and users. By helping to inform decision-makers worldwide about available greenhouse gas technologies, GREENTIE will contribute to increased exports and unit sales of energy-efficient products and will help to reduce the adverse impacts of fossil fuel consumption on the global environment.

At present, 19 member countries participate in GREENTIE: thirteen are members of IEA; the remaining nations are developing countries from around the world. The GREENTIE Center in the Netherlands acts as a focal point for information and technology sharing between these 19 countries.

GREENTIE Member Country

Nineteen countries have joined the Greenhouse Gas Technology Information Exchange (GREENTIE).

GREENTIE's primary product will be a directory of information about suppliers of products, technologies, and information related to the mitigation of greenhouse gases. In October 1995, the GREENTIE Center in the Netherlands is scheduled to complete the first edition of a directory of this

supplier information and will make the directory available to all member countries. The directory will categorize the capabilities of suppliers along five dimensions: (1) the greenhouse gases that their products and technologies help to mitigate, (2) the economic activities of the users of their products and technologies, (3) the types of greenhouse gas technologies that they supply, (4) the technology's life cycle, and (5) the products and services that they offer. During 1995, ORNL will contribute directory information on 2,500 organizations located in the United States.

Center for the Analysis and Dissemination of Demonstrated Energy Technologies.

CADDET was formed by IEA in 1988 to collect and disseminate information on demonstrated, energy-efficient technologies. The ultimate goal of DOE involvement in the CADDET program is to assist U.S. companies by promoting their energy-efficient technologies to potential new markets within and outside the United States. In addition, CADDET strives to make information on other countries' demonstrated energy technologies available to domestic decision-makers. A final key CADDET goal is to contribute to an international effort to reduce the adverse environmental impacts of fossil fuel consumption through energy conservation. In the United States, ORNL coordinates involvement with the CADDET Energy Efficiency Annex for DOE.

At the heart of the CADDET operation is the computerized Register of information on more than 1,600 energy technology demonstration projects. Each member country is responsible for preparing Register entries covering demonstrations in their countries. A majority of these entries focus on technologies for increasing the efficiency of energy use in buildings and industrial processes. Agriculture, transportation, utilities, and other end uses are also represented, but to a lesser degree. A total of 317 entries describe U.S. demonstration projects. CADDET also produces technical brochures, which provide expanded information on key technologies represented in the CADDET Register; analysis reports, which compare the technical and economic results of selected demonstration projects on a particular technology; and quarterly newsletters, which are currently distributed to over 10,000 subscribers world-wide.

The project has been instrumental in meeting the information needs of a wide array of audiences, as indicated by the following quotes provided during a recent survey of newsletter subscribers:

"CADDET has provided leads on advanced industrial technology applications that we have used to identify alternative approaches that our managers can use." —Pacific Gas and Electric Company.

"We use the newsletter as an overview of research and efficiency improvement potential for all sectors of the economy." —Boeing Company.

"We use many of your articles in training our energy systems engineers." —General Electric.

"Geothermal and renewable resource articles have given us contacts in Denmark, Finland and elsewhere. We have made site visits and shared findings." —State of Oregon Department of Energy.

IEA Heat Pump Program. DOE's Office of Building Technologies sponsors the U.S. participation in the IEA Implementing Agreement for a Program of Research, Development, Demonstration and Promotion of Heat Pumping Technologies, or IEA Heat Pump Program. ORNL's Buildings Technology Center provides technical and administrative support to the IEA Heat Pump Program and chairs

the group of experts that comprise the U.S. National Team. International collaboration and technology transfer is made possible by the volunteer efforts of each country's National Team. The U.S. National Team has strong industry representation from Carrier Corporation, Electric Power Research Institute, Gas Research Institute, Inter-City Products, Lennox Industries, and The Trane Company, to name a few.

Since 1978, more than twenty Annexes, or collaborative projects, have been sponsored by the IEA Heat Pump Program. Up to sixteen countries participate in the Annexes, which contribute to improved heat pumping technologies. The U.S. is the designated Operating Agency for two active annexes: Annex 18, *Thermophysical Properties of the Environmentally Acceptable Refrigerants*; and Annex 21, *Global Environmental Benefits of Industrial Heat Pumps*. Included in the products resulting from Annex 21 is a computer program to project the market penetration, potential energy savings, and potential emissions reductions of industrial heat pumps.

Annex 16, The Heat Pump Center (HPC), provides a means of collecting, analyzing, and disseminating heat pump related technical, market, regulatory, and environmental information. Specifically, it publishes the quarterly journal *IEA Heat Pump Center Newsletter*, organizes workshops, provides an inquiry service, and conducts analysis studies on selected heat pump topics. Each member country recently submitted national position papers for an analysis report entitled *International Heat Pump Status and Policy Review* (HPC-AR3). Other recent multinational analysis projects have focused on heat pump water heaters and the impact of heat pumps on global climate change. The HPC's quarterly journal is distributed to over 800 readers in the U.S., and to more than 4,000 readers worldwide. Proceedings of two recent HPC cosponsored international workshops are also now available: *Consequences of (H)CFC Replacement in HVAC Applications* and *Utilities Perspectives on Heat Pumps for Retrofit and New Applications in Buildings*.

SUPPORT FOR INTERNATIONAL INITIATIVES

A recent area of DOE leadership has been in promoting international sustainable energy and trade. In a time of national concern about global economic competitiveness and global environmental change, the Department is working in partnership with U.S. industry to increase exports of environmentally sound technologies and services, and it is encouraging program initiatives such as international joint implementation that seek effective international cooperation in assuring environmental sustainability. Much of this effort is focused on such key countries for trade and fossil fuel emissions as China, India, and Russia.

For nearly a decade and a half, ORNL has been developing a base of knowledge and experience with energy and environmental collaboration in developing countries and emerging economies. Since 1982, the Laboratory has led more than sixty projects in more than thirty countries in Africa, Asia, Eastern Europe and the former Soviet Union, Latin America and the Caribbean, and the Middle East — many of them in association with U.S. and endogenous private-sector firms. Recognizing the value of this expertise, developed by ORNL in anticipation of DOE needs, Secretary O'Leary invited Tom Wilbanks of ORNL to accompany her on two trips to India in 1994-95 and to assist DOE in its India action planning; and she invited Milton Russell of ORNL and the University of Tennessee to accompany her on her recent mission to China.

ORNL's experience in developing countries and emerging economies with energy efficiency

and renewable energy sources has been both diverse and significant. For example:

- **Building Technologies.** Besides broad assessments of end-use efficiency improvement potentials in developing countries, ORNL has pioneered an approach to technology adaptation for foreign markets, applied first to improving the efficiency of home refrigerators in India (see highlight next page), that combines Laboratory R&D skills with industry participation to open doors for increasing U.S. market shares in major developing economies.
- **Transportation Technologies.** For a decade, ORNL has played a pathbreaking role in improving the understanding of strategies for energy efficiency improvement in the transportation systems of developing countries, linked with such other issues as urban air pollution and traffic congestion. David Greene, Frank Southworth, and Glen Harrison are recognized research contributors, having analyzed transportation issues in such countries as Costa Rica, Tunisia, Bangladesh, India, and Korea.
- **Utility Technologies: Efficiency Improvement.** ORNL has been active in promoting electric utility planning and management approaches that encourage system-wide energy efficiency improvement. For example, one of ORNL's projects in China is institutionalizing an integrated resource planning (IRP) process in Hainan by transferring IRP methods, models, and technologies to staff of the Hainan Electric Power Company (HEPCO). Implementation of an IRP process will result in major near-term electric energy and capacity savings in Hainan. The longer-term benefits should be even more substantial, since a secondary activity of the work will be to use the Hainan experience as a framework for transferring the IRP process to other Chinese cities and provinces. In Russia, ORNL is working with staff of Russian utilities to adapt Western methods of electric-power planning, including its accounting and financial bases. This project will help Russian utility managers account for the financial and technical differences of alternative resources when making procurement decisions. In addition, the Laboratory has been involved in monitoring and assessing rural electrification programs in several developing regions.
- **Utility Technologies: Renewable Energy.** ORNL has also been a leader in promoting renewable energy use in developing countries. For instance, a landmark analysis of village electrification in the Dominican Republic, based on photovoltaic energy, led to a major new initiative to improve the availability of financing for decentralized small-scale renewable energy use. The Laboratory's emphasis, however, has been on biomass energy systems. In China, an assessment of biomass plantations as feedstocks for electricity in Yunnan Province has led rapidly to facility development (see highlight, page 82), and ORNL is participating in feasibility studies in India as well. Moreover, ORNL has examined improved cookstoves and new sources of briquette fuels in Africa, Asia, and Latin America, both stimulating business activity and seeking to learn lessons from the experience.

In these connections and others, ORNL has assisted in establishing the Committee on Energy Efficiency Commerce and Trade (COEECT) and has assisted DOE in energy efficiency aspects of U.S.

TECHNOLOGY ADAPTATION AND MARKET CONDITIONING IN INDIA

The India Refrigerator Project is a particularly good example of a distinctive role for a national laboratory in international technology cooperation. Although India has a total population of about 850 million, including the largest middle class of any single country in the world, only about 9 million refrigerators are currently used in Indian homes. The number of home refrigerators is growing at a rate of more than 20% per year, and the market for refrigerator sales in India over the next several decades will be enormous, growing to a forecasted 110 million units in use by 2010. Meanwhile, in September 1992, India signed the Montreal Protocol and has eased its restrictions on the activities of foreign firms within India, including U.S. firms.

In light of all these emerging trends, DOE/ADEPT and US-AEP initiated a collaborative U.S./Indian effort to identify and implement refrigeration technologies for the Indian market that will reduce CFC emissions, aiming toward commercial development through U.S./Indian private sector joint ventures. If successful, the results would amount to a win-win situation for both the United States and India (1) by

reducing CFC emissions associated with a rapidly growing source and other greenhouse gas emissions from the electric power generation, largely based on coal; and (2) by opening up opportunities for U.S. firms in meeting Indian consumer demands in a very large, rapidly emerging energy technology market.

The project includes two major components, both in collaboration with Tata Energy Research Institute (TERI): technology adaptation, led by ORNL, and market conditioning, led by the International Institute of Energy Conservation. Over the past several years, ORNL helped carry out a U.S. industry familiarization visit to India, the testing at ORNL of several representative Indian refrigerators to enable a preliminary assessment of efficiency improvement potentials, an Indian industry familiarization visit to the United States, and a joint U.S./Indian, public/private sector identification of technology strategies and roles. On the market conditioning side, the development and implementation of appliance performance standards in India are being explored, along with a prototype program for an electricity DSM strategy in a candidate Indian state.

Indian home refrigerators like these (manufactured by Kelvinator, Ltd., in Faridabad, India) are only about half as efficient as comparable U.S. refrigerators.

participation in the Asia-Pacific Economic Cooperation (APEC) agreement. APEC was created in 1989 to promote the economy and social well-being of the Asia-Pacific region. Its Energy Working Group was established to maximize the energy sector's contribution to the region's economic and social well-being. One of its major efforts is the Expert Group on Energy Efficiency and Conservation (EE&C). ORNL provides technical support to DOE's involvement in this group. At the request of the EE&C expert group, ORNL has produced two reports—one concerning energy efficiency and conservation in the food and beverage industry in the region, the other a compendium of energy efficiency and conservation policies, regulations, and standards of all the APEC member economies.

In addition to these accomplishments, the EE&C expert group has conducted a DSM workshop for the Asia-Pacific region and formed an Inter-Utility DSM Liaison Group comprised of utility representatives from each of the APEC member economies. In May 1995, ORNL will convene a workshop on urban transportation issues in Malaysia. The workshop will provide an opportunity for APEC members to share their experiences in solving environmental, energy, and technology-related problems in urban transportation. A major objective of the workshop is to establish a continuing liaison group to identify opportunities for cooperation among APEC members on these issues, develop proposals, and pursue funding to support cooperation.

INNOVATIVE USES OF BIOMASS ENERGY IN CHINA

Meeting the growing needs for energy services among China's 1.1 billion population without dramatically increasing coal use is one of the highest priorities for balancing international development and environmental management concerns. China's energy-supply alternative to coal that has received the least systematic attention is biomass production and conversion. Two very recent developments indicate the potential for this option in China. First, at the suggestion of Milton Russell of ORNL, a team conducted a 1990 feasibility study of the utilization of short-rotation, plantation-grown

trees for electricity production in Yunnan Province, supported by DOE's Committee on Renewable Energy Commerce and Trade (CORECT) program. Based on that study, the Chinese decided to pursue a major biomass electricity program in this region. Two sites were identified for biomass plantations, and Chinese investment funds were allocated. The only long-term need for foreign involvement was relatively low-level technical assistance — a sizeable payoff indeed from a small feasibility study. More recently, a U.S. private sector firm has followed up this opening, seeking to promote biomass energy.

REFERENCES, CONTACTS, AND ACKNOWLEDGMENTS

BUILDING TECHNOLOGIES

Baxter, V. D., et al. 1988. "Ground Coupled Heat Pumps for Northern Climates," *Engineer*, April, pp. 69-76.

Baxter, V. D., F. A. Creswick, and W. K. Snelson. 1993. "Heat Pump Technology: Responding to New Opportunities," pp. 563-72 in *Heat Pumps for Energy Efficiency and Environmental Progress: Proceedings of the 4th International Energy Agency Heat Pump Conference, Maastricht, Netherlands, April 26-29, 1993*, Elsevier Science Publishing, Amsterdam, N.Y.

Carmody, J., J. Christian, and K. Labs. 1991. *Builder's Foundation Handbook*, ORNL/CON-295, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Christian, J. E., and M. K. Voss. 1992. *A Study of Changes in Foundation Insulation Levels in the United States*, ORNL/CON-351, Oak Ridge National Laboratory, Oak Ridge, Tenn.

DeVault, R. C., and G. Grossman. 1993. *Facts About Triple-Effect Absorption Chiller Cycles Gas Industries*.

Fischer, S. K., P. D. Fairchild, and P. J. Hughes. 1992. "Global Warming Implications of Replacing CFCs," *ASHRAE Journal* 34(4), 14-19.

Fischer, S. K., C. K. Rice, and W. L. Jackson. 1988. *The Oak Ridge Heat Pump Design Model: Mark III Version Program Documentation*, ORNL/TM-10192, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Graves, R. S., K. E. Wilkes, and D. L. McElroy. 1994. *Thermal Resistance of Attic Loose-Fill Insulations Decreases Under Simulated Winter Conditions*, ORNL/M-3253, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Hughes, P. J. 1993. "Space Conditioning Options in the North: What Is Here and What May Come," *DSM Quarterly*, pp. 11-20.

Hughes, P. J., and R. J. Hackner. 1988. *Field Performance Validation of an Advanced Design Earth-Coupled Heat Pump System*, ORNL/Sub/85-22035/1, Oak Ridge National Laboratory, Oak Ridge, Tenn.

International Energy Agency. 1994. *A Guidebook for Insulated Low-Slope Roof Systems*, Buildings and Community Systems Committee, International Energy Agency Annex 19, Low-Slope Roof Systems, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Lstiburek, J., and J. Carmody. 1991. *Moisture Control Handbook: New, Low-Rise Residential Construction*, ORNL/Sub/89-SD350/1, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Mei, V. C. 1986. *Horizontal Ground-Coil Heat Exchanger Theoretical and Experimental Analysis*, ORNL/CON-193, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Myers, G. H., et al. 1993. "Gas-Fueled Space Conditioning Heat Pump Research in the United States," *Heat Pumps for Energy Efficiency and Environmental Progress: Proceedings of the 4th International Energy Agency Heat Pump Conference, Maastricht, Netherlands, April 26–29, 1993*, Elsevier Science Publishing, Amsterdam, N.Y.

Rice, C. K., and J. R. Sand. 1993. "Compressor Calorimeter Performance of Refrigerant Blends—Comparative Methods and Results for a Refrigerator/Freezer Application," *ASHRAE Transactions* **99**(1), 1447–66.

Sand, J. R., E. A. Vineyard, and R. J. Novak. 1990. "Experimental Performance of Ozone-Safe Alternative Refrigerants," *ASHRAE Transactions* **96**(2), 173–81.

Svec, O. J., and V. D. Baxter. 1993. "Heat Pump Systems With Direct Expansion Ground Coils," pp. 40-1–40-21 in *Proceedings: Meeting Customer Needs with Heat Pumps, Dallas, October 15-19, 1991*, EPRI/TR-101944, Palo Alto, Calif.

U.S. Department of Energy. 1994. *Rebuilding Your Flooded Home: Guidelines for Incorporating Energy Efficiency*, Office of Building Technologies, Energy Efficiency and Renewable Energy, DOE-EE-0019, May.

Vineyard, E. A., J. R. Sand, and T. G. Statt. 1989. "Selection of Ozone-Safe, Nonazeotropic Refrigerant Mixtures for Capacity Modulation in Residential Heat Pumps," *ASHRAE Transactions* **95**(1), 34–46.

Vineyard, E. A. and J. R. Sand. 1995. "Evaluation of Design Options for Improving the Energy Efficiency of an Environmentally Safe Domestic Refrigerator-Freezer," *ASHRAE Transactions*, **101**(1).

Wilkes, K. E., and P. W. Childs. "Thermal Performance of Clean Horizontal Radiant Barriers Under Winter Conditions: Laboratory Measurements and Mathematical Modeling," *ASHRAE Transactions* **99**(1), 603–13.

TRANSPORTATION TECHNOLOGIES

Davis, S. C., and S. G. Strang. 1993. *Transportation Energy Data Book*, 13th ed., ORNL-6743, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Downing, M., and R. L. Graham. 1993. *Evaluating a Biomass Resource: The TVA Region-Wide Biomass Resource Assessment Model*, Proceedings of the First Biomass Conference for the Americas—Energy, Environment, Agriculture, and Industry, August 30–September 2, 1993, Burlington, Vermont.

Greene, D. L. 1994. *Alternative Fuels and Vehicles Choice Model*, ORNL/TM-12738, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Greene, D. L., and P. N. Leiby. 1993. *The Social Costs to the U.S. of Monopolization of the World Oil Market, 1972–1991*, ORNL-6744, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Hansen, E., et al. 1994. *Short Rotation Woody Crop Trials for Energy Production in North Central U.S. 1992 Annual Report*, ORNL/M-3220, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Keyes, B. L. P. 1994. *Ceramic Technology Project Database: September 1993 Summary Report*, ORNL/M-3155, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Mei, V. C., F. C. Chen, and D. M. Kyle. 1992. *Alternative Non-CFC Mobile Air Conditioning*, ORNL/CON-335, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Mei, V. C., F. C. Chen, and R. Sullivan. 1991. "Analysis of Non-CFC Automotive Air Conditioning," *Proceedings of the 1991 International CFC and Halon Alternatives Conference, December 3-12, 1991, Baltimore, Md.*

Pasto, A. E., and S. Natansohn. 1992. *Development of Improved Processing Methods for High Reliability Structural Ceramics for Advanced Heat Engines*, ORNL/Sub/89-SD548/1, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Southworth, F. and D. W. Jones. 1995. *Travel Reduction Through Changes in Urban Spatial Structure: A Search for Policy Instruments in Support of Cleaner, More Energy Efficient Cities*, Prepared for the Office of Energy Efficiency and Renewable Fuels Policy, U.S. Department of Energy, February draft.

U.S. Department of Energy. 1993. *Lightweight Materials for Transportation: Program Plan*, Office of Transportation Materials, Energy Efficiency and Renewable Energy, ORNL/ATD-75, Oak Ridge National Laboratory, Oak Ridge, Tenn.

U.S. Department of Energy. 1994. *Energy, Emissions, and Social Consequences of Telecommuting*. Energy Efficiency in the Economy Technical Report 1, DOE/PO-0021, Department of Energy, Office of Policy, Planning, and Program Evaluation, Washington, D.C.

Winslow, S. G. 1994. *Materials Development Program Ceramic Technology Project Bibliography (1984-1992)*, ORNL/M-3201, Oak Ridge National Laboratory, Oak Ridge, Tenn.

INDUSTRIAL TECHNOLOGIES

Ally, M. R. 1992. "Methods for Predicting Properties and Tailoring Salt Solutions for Industrial Processes," in *Technology 2002: Proceedings of the Third National Technology Transfer Conference and Exposition, December 1-3, 1992*, NASA-CP-3189, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Anon. December 1994. "Fridge of the Future," *Mechanical Engineering*, pp. 76-80.

Davison, B. H., and C. D. Scott. 1993. "Advanced Bioreactors for Enhanced Production of Chemicals," *Preprints*, 38(2), 304-7 (205th National Meeting, American Chemical Society, Denver, March 28-April 2, 1993),

Davison, B. H., and J. E. Thompson. 1992. "Simultaneous Fermentation and Separation of Lactic Acid

in a Biparticle Fluidized Bed Bioreactor,” *Applied Biochemistry and Biotechnology* **34/35**, 431–39.

Keiser, J. R., et al. 1993. *High-Temperature Corrosion of Ceramic-Ceramic Composites in a Waste Incinerator Environment*, ORNL/TM-12212, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Lauf, R. J., et al. 1993. “2 to 18 GHz Broadband Microwave Heating Systems,” *Microwave Journal* **36**(11), 24.

Liu, C. T., and K. S. Kumar. 1993a. “Ordered Intermetallic Alloys. Part I: Nickel and Iron Aluminides,” *JOM* **45**(5), 38.

Liu, C. T., and K. S. Kumar. 1993b. “Ordered Intermetallic Alloys. Part II: Silicides, Trialuminides, and Others,” *JOM* **45**(6), 28.

Loutfy, R. O., J. C. Withers, and D. Chakravarti. 1993. *Technology and Market Assessment of Silicon Carbide Whisker Reinforced Alumina Heat-Exchanger Tubes*, ORNL/Sub/85-SE793C/1, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Oak Ridge National Laboratory. In press. *Materials Needs and Opportunities in the Pulp and Paper Industry*, ORNL/TM-12865.

Woodward, J., et al. 1994. “Enzymatic Separation of High-Quality Uninked Pulp Fibers from Recycled Newspaper,” *Biotechnology* **12**, 905–8.

UTILITY TECHNOLOGIES

Baxter, L., and E. Hirst. 1995. *Estimating Potential Stranded Commitments for U.S. Investor-Owned Electric Utilities*, ORNL/CON-406, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Dresner, L. 1994. “On the Connection Between Normal Zone Voltage and Hot-Spot Temperature in Uncoiled Magnets,” *Cryogenics* **34**(2), 111–18.

Dull, R. W., and H. R. Kerchner. 1993. *A Teacher’s Guide to Superconductivity for High School Teachers*, ORNL/M-3063, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Hawsey, R. A., et al. 1994. “Progress in Development of High Temperature Superconducting Wire for Electric Power Applications.” Paper submitted to the 29th International Energy Conversion Engineering Conference, Monterey, Calif.

Hirst, E. 1993. *Statistical Recoupling: A New Way to Break the Link Between Electric-Utility Sales and Revenues*, ORNL/CON-372, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Kroeger, D. M., et al. 1994. “Local Texture and Percolative Paths for Long-Range Conduction in High Critical Current Density $\text{TiBa}_2\text{Ca}_2\text{Cu}_3\text{O}_{8+x}$ Deposits,” *Applied Physics Letters* **64**(1), 106–8.

Sharp, T., and H. R. Kerchner. 1994. *An Introduction to Cryogenics and Superconductivity for Junior High/Middle School Students*, ORNL/M-3785, Oak Ridge National Laboratory, Oak Ridge, Tenn.

CROSS-CUTTING PROGRAMS

Brown, M. A., and L. G. Berry. 1995. "Determinants of Cost-Effectiveness: Results of the National Weatherization Evaluation," *Energy-The International Journal*, forthcoming.

Brown, M. A., L. G. Berry, and L. F. Kinney. 1994. *Weatherization Works: Final Report of the National Weatherization Evaluation*, ORNL/CON-395, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Brown, M. A., et al., *The Economic, Energy, and Environmental Impacts of of the Energy-Related Inventions Programs*, ORNL/CON-381, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Hill, L.J. 1993. "Electric Power, Economic Development, and the Environment in Hainan Province, China," *Asian Journal of Environmental Management*, 1(2), 67-76.

Wilbanks, T. J. 1994. "'Sustainable Development' in Geographic Context," *Annals of the Association of American Geographers*, 84(4), 541-57.

Wilbanks, T. J. 1994. "Energy Efficiency Improvements: Making a No Regrets Option Work," *Environment*, 36(9), 16-20,34-44.

CONTACTS

For more information on Oak Ridge National Laboratory's Energy Efficiency and Renewable Energy Program, please contact us:

Anthony C. Schaffhauser, Program Director
(615) 574-4826
schaffhausac@ornl.gov

Marilyn A. Brown, Deputy Program Director
(615) 576-8152
brownma@ornl.gov

Kathi H. Vaughan, Administrative Assistant
(615) 241-4292
vaughanhk@ornl.gov

You can reach us via facsimile at (615) 576-7572

Our mailing address is

Energy Efficiency and Renewable Energy Program
Oak Ridge National Laboratory
Post Office Box 2008
Oak Ridge TN 37831-6186

ORNL's Energy Efficiency and Renewable Energy Program now has a World Wide Web (WWW) home page, also accessible from the ORNL home page. The WWW makes it possible to send and receive text, video, audio, and all types of graphics (including photographs) over the Internet. Software programs called "browsers" (for example, Mosaic or Netscape) make it possible to view and manage this information. Through WWW and the browser, Internet users can access ORNL's hypertext documents, gopher databases, library catalog, publications list, and Quicktime movies. All that's required is a networked computer (Macintosh, PC, or UNIX) and the browser program. Our WWW address (universal resource locator, or URL) is

http://www.ornl.gov/ORNL/Energy_Eff/Energy_Eff.html

From the program's home page, users can view, save, and print text and graphics that describe ongoing projects, browse news releases, fact sheets, and other documents, and view and perform keyword searches on databases of publications and technologies. All information is linked through hypertext, making it easy to find related topics or articles.

ACKNOWLEDGMENTS

In the course of preparing this document, many of the program managers and scientists working in ORNL's EE/RE Program have contributed material describing their activities. Their cooperation is greatly appreciated. We also wish to thank Ed Lapsa for his invaluable help with the document's page layout and graphics.

Buildings Technologies

Program Area or Project Name	Contact(s)	Telephone	Facsimile	E-mail*
Building Envelope Systems	Jeffrey E. Christian	615/574-5207	615/574-9338	christianje
Building Materials	Kenneth E. Wilkes	615/574-5931	615/574-9338	wilkeske
Heating and Cooling Equipment	Phillip D. Fairchild	615/574-2020	615/574-9338	fairchildpd
Thermally Activated Heat Pumps	Robert C. DeVault	615/574-0738	615/574-9338	devaultrc
Ground-Coupled Heat Pumps	Patrick J. Hughes	615/574-9337	615/574-9338	hughespj1
Refrigeration Systems	Van D. Baxter	615/574-2104	615/574-9338	baxtervd
Existing Buildings	Mike MacDonald Mark P. Ternes	615/574-5187 615/574-0749	615/574-9338 615/574-9338	macdonaldjm ternesmp
Technology Transfer	Pat M. Love	615/574-4346	615/574-9338	lovepm

Transportation Technologies

Program Area or Project Name	Contact(s)	Telephone	Facsimile	E-mail*
Partnership for a New Generation of Vehicles	Richard E. Ziegler	615/574-5149	615/576-7572	zieglerre
Ceramic Technology	D. Ray Johnson	615/576-6832	615/574-6098	johnsondr
Lightweight Materials	Philip S. Sklad Geoffrey M. Wood	615/574-5069 615/576-9693	615/574-6098 615/574-9407	skladps woodgm
Biofuels Feedstock Development	Janet H. Cushman	615/574-7818	615/576-8143	cushmanjh
Alternative Fuels Utilization	Ronald L. Graves	615/574-2036	615/574-2102	gravesrl
Bioreactors for Alcohol Fuel Production	Timothy C. Scott	615/574-5962	615/574-6442	scotttc
Automotive Propulsion Technology	Ronald L. Graves	615/574-2036	615/574-2102	gravesrl
Environmental Control Technology	Fang C. Chen	615/574-0712	615/574-9338	chenfc
Transportation Data And Policy Analysis	Michael S. Bronzini	615/574-8267	615/574-3895	bronzinims

*Add the following extension to each of these addresses: "@ornl.gov".

Industrial Technologies				
Program Area or Project Name	Contact(s)	Telephone	Facsimile	E-mail*
Advanced Industrial Materials	Peter Angelini Philip S. Sklad	615/574-4565 615/574-5069	615/574-6098 615/574-6098	angelinip skladps
Advanced Bioprocessing Concepts	Timothy C. Scott	615/574-5962	615/574-6442	scotttc
Thermal Science	Fang C. Chen	615/574-0712	615/574-9338	chenfc
Alternative Feedstocks	Brian H. Davison	615/576-8522	615/574-6442	davisonbh
Pulp and Paper Processes	Peter Angelini	615/574-4565	615/574-6098	angelinip
Continuous Fiber Ceramic Composites	Michael A. Karnitz	615/574-5150	615/574-6098	karnitzma
Advanced Industrial Heat Exchangers	Michael A. Karnitz	615/574-5150	615/574-6098	karnitzma
Industrial Heat Pumps	Mitchell Olszewski	615/574-0770	615/574-2032	olszewskim
Advanced Turbine Systems	Michael A. Karnitz	615/574-5150	615/574-6098	karnitzma
Energy-Efficient Motors and Drive Systems	Mitchell Olszewski	615/574-0770	615/574-2032	olszewskim

Utility Technologies				
Program Area or Project Name	Contact(s)	Telephone	Facsimile	E-mail*
Power Systems Technology	Jim Van Coevering	615/574-4829	615/574-9338	vancoeverinj
Superconductivity Partnerships Program	Robert Hawsey	615/574-8057	615/574-6073	hawseyra
Hydrogen Production and Fuels Infrastructure	Suman Singh	615/574-6639	none listed	singhsp
Renewable Energy Conversion	Mike Sale	615/574-7305	615/576-8543	salemj
Thermal Energy Storage	Mitchell Olszewski	615/574-0770	615/574-2032	olszewskim
Electric Industry Policy Studies	Eric Hirst	615/574-6304	615/576-8745	hirstea

*Add the following extension to each of these addresses: "@ornl.gov".

Cross-Cutting Activities

Program Area or Project Name	Contact(s)	Telephone	Facsimile	E-mail*
Weatherization Assistance Program	Doug C. Bauer Linda G. Berry	202/479-2689 615/574-5949	202/479-0575 615/574-4747	bauerdc berrylg
National Energy Audit	Mike Gettings	615/574-4506	615/574-9338	gettingsmb
Energy-Related Inventions Program	Marilyn A. Brown	615-576-8152	615-576-7572	brownma
Developing Countries	Thomas J. Wilbanks	615/574-5515	615/576-2943	wilbankstj
CADDET	Marilyn A. Brown	615/576-8152	615/576-7572	brownma
GREENTIE	Melissa K. Voss	615/574-1013	615/574-9338	vossmk
APEC	Doug Bauer	202/479-2689	202/479-0575	bauerdc

User Facilities

Program Area or Project Name	Contact(s)	Telephone	Facsimile	E-mail*
Building Technology Center	George E. Courville	615/574-1945	615/574-9338	gec
Bioprocessing Research & Development Center	Brian H. Davison	615/576-8522	615/574-6442	davisonbh
High Temperature Materials Laboratory	Arvid E. Pasto	615/574-5123	615/574-6098	pastoae

*Add the following extension to each of these addresses: "@ornl.gov".