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Global Warming

Energy Use

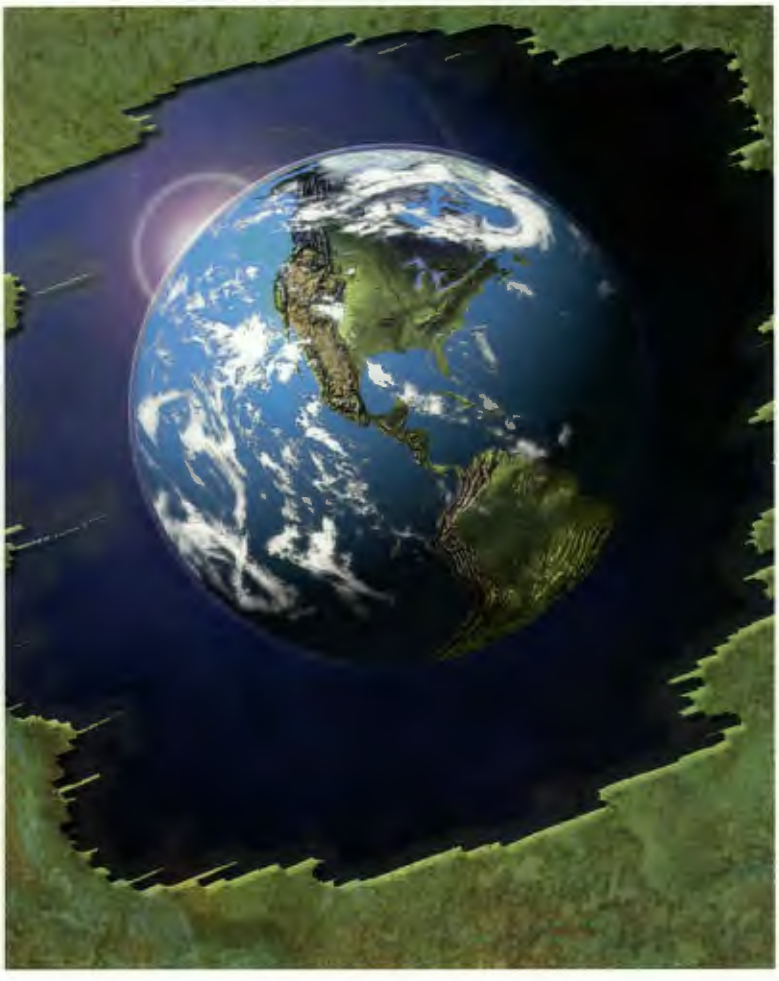
Transportation Efficiency

Electric Utilities

Developing Regions

Energy and Global Climate Change

ORNL's Center For Global Environmental Studies



COVER CAPTION

In his depiction of the greenhouse effect, artist Mitchell Williamson helps us peer through the glass at the globe (earth artwork created by Bob Zerby). Will we have global climate change? How will it affect forests and fields? Can we slow our growth in energy use to slow global warming? These questions are being probed at ORNL, as described in this special issue of the *Review* on "Energy and Global Climate Change."

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FEATURES

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Oak Ridge National Laboratory is a multiprogram, multipurpose laboratory that conducts research in energy production and end-use technologies; biological and environmental science and technology; advanced materials synthesis, processing, and characterization; and the physical sciences including neutron-based science and technology.

Energy and Global Climate Change: Why ORNL ?

By Michael P. Farrell

Subtle signs of global warming have been detected in studies of the climate record of the past century after figuring in the cooling effects of sulfur emissions from volcanoes and human sources. According to the December 1995 report of the Intergovernmental Panel on Climate Change (IPCC), the earth's surface temperature has increased by about 0.2°C per decade since 1975. The panel projects about a 2° increase in global temperature by 2100. ■ The IPCC report states that pollutants—greenhouse gases such as carbon dioxide and fluorocarbons that warm the globe and sulfur emissions that cool it—are responsible for recent patterns of climate change. "The balance of evidence," states the report, "suggests that there is a discernible human influence on global climate." This human influence stems largely from fossil fuel combustion, cement production, and the burning of forests, and it could intensify as populations grow and developing countries increase energy production and industrial development. ■ Two facts have caught the attention of the news media and public. First, 1995 was declared the hottest year in the 140-year-long record of reliable global measurements. Second, recent

years have been marked by an unusually high number of extreme weather events, such as hurricanes, blizzards, and floods. In the 1990s, the world has become more aware of the prospect and possible impacts of global climate change.

In the late 1950s, global climate change was an unknown threat to the world's environment and social systems. Except for a few ORNL researchers who had just completed their first briefing to the U.S. Atomic Energy Commission (AEC) on the need to understand the global carbon cycle, the connection between rising carbon dioxide concentrations and potential changes in global climate was not common knowledge, nor were the consequences of climate change understood. It would not be until almost 15 years later—the mid-1970s—that a comprehensive Department of Energy (DOE) research program was established to study the effects of increased atmospheric carbon dioxide concentrations on the world's climate—the first global climate change program. DOE provided the leadership of the program.

How did this happen? Oak Ridge had an important impact on the U.S. government's role in recognizing and offering solutions to the problem of carbon dioxide and climate. Former ORNL Director Alvin Weinberg was instrumental in bringing the problem of carbon dioxide's effects on climate to the attention of the government. Weinberg had learned from Jerry Olson, an ORNL ecologist, about the need to better understand green plants' role in the global carbon budget. Weinberg was the first to alert the Energy Research and Development Administration (ERDA), the AEC's successor and the DOE's predecessor, to the potential of increased coal combustion to alter the climate in undesirable ways. The head of ERDA then established a carbon dioxide effects office in 1975. ERDA gave the new Institute for Energy Analysis (IEA) that Weinberg had established in Oak Ridge the responsibility of assessing the impacts of increased atmospheric concentrations of carbon dioxide. A few years later, ORNL and other national laboratories were addressing many aspects of what Vice President Al Gore calls "the most serious problem our civilization faces" or as other folks put it, "the granddaddy of all environmental issues." ORNL gained a leadership role for studies of the global carbon cycle, and Dave Reichle and John Trabalka here directed the national program through DOE.

Why does DOE have the lead? Energy and the environment are inextricably linked. The main source of atmospheric carbon dioxide increases is human activities (anthropogenic sources) with the majority coming from power generation. From a small national program, DOE and laboratory leadership brought the question of global climate change to the forefront of the international research community. Today, seven years after the congressional testimony during the sweltering summer of 1988, the U.S. Global Change Research Program is nearly a $2 billion enterprise encompassing 12 U. S. agencies examining the full range of global change issues. DOE remains a dominant participant in this research enterprise.

But what prompted this buildup of a large, multiagency U.S. research program in global change? One of the major drivers took place in June 1992. Beginning in the late 1980s, there was a growing international consensus that the world had a problem of unprecedented proportions—a strong possibility exists that the world's climate may change—becoming warmer by most calculations. The world was now ready to act as more than 200 nations participated in the historic United Nations Conference on Environment and Development, which included the Framework Convention on Climate Change, held in Rio de Janeiro, Brazil. Dave Reichle, Paul Kanciruk, and I were delegates at the conference. Two decades of research experience working with DOE to understand global climate change proved to be a valuable commodity at the convention. ORNL's analyses of global carbon dioxide emissions, sources and sinks of the global carbon cycle, energy efficiency alternatives, and the effect of climate change on ecosystems were all part of the fabric of understanding that led to the conference.

Almost all the countries at the conference, including the United States, signed a treaty that called on all nations to work together in an unprecedented effort to protect the global environment. Specifically, the industrialized countries were urged to take the lead by

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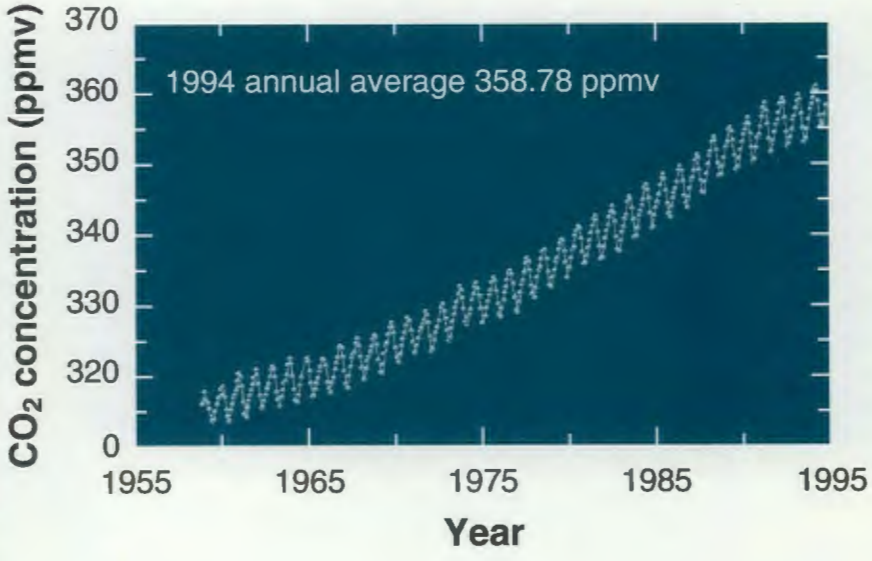


According to measurements taken at the Mauna Loa volcano in Hawaii, the concentration of carbon dioxide in the earth's atmosphere is steadily rising. This increase is a concern because atmospheric carbon dioxide keeps heat radiated from the sun-warmed earth from escaping into space.

stabilizing greenhouse gas emissions to 1990 levels by the year 2000.

Unraveling the consequences of rising atmospheric greenhouse gases is not a task for a single institution or individual principal investigator. Unlike most research programs addressing complex issues that tend to be highly competitive, understanding the causes and effects of rising carbon dioxide concentrations requires collaborative interdisciplinary efforts. ORNL's global climate change researchers have been fortunate over the past 20 years to work with the best and the brightest both within ORNL and with private and university-based research groups. Our research successes have depended on many other projects and analyses conducted by interdisciplinary teams of researchers. Out of these collaborative efforts, however, ORNL can take pride in research findings, products, and understanding that have emerged from studies centered at the Laboratory. In brief, among our major contributions, we have:

- Established the standard methodology by which global estimates of atmospheric carbon dioxide emissions are calculated.
- Developed a systems view needed to integrate the cumulative effects of carbon dioxide, chlorofluorocarbons, and other important greenhouse gases.
- Demonstrated the promise of massively parallel computing to simulate future climate more rapidly than other computing platforms.
- Showed that terrestrial ecosystems (forests, vegetation, soil) have a central role in the global carbon cycle and that these ecosystems respond very quickly to climatic events such as El Niño, the periodic ocean-warming phenomenon.
- Confirmed the physiological mechanisms that control enhanced carbon uptake by and productivity of forests.
- Integrated socioeconomic and ecological factors to predict causes and effects of land-use changes (i.e., deforestation) in tropical regions.
- Analyzed how global decisions are made and how to influence the decision-making process.
- Developed approaches for reducing carbon dioxide emissions through policy instruments addressed at the private sector, changing the energy mix of developed and developing nations, incorporating biomass as an alternative fuel, and implementing energy efficiency improvements.
- Built integrated assessment approaches to evaluate the consequences of global climate change through new tool developments such as systems ecology, risk assessment, evaluation analysis, and engineering systems analysis.

From these past successes comes the hope of transferring our capabilities derived from research on global change issues to new challenges resulting from sustainable development goals. New methodologies such as industrial ecology, life-cycle assessment, and economic ecology evaluations should help ORNL develop opportunities to guide

the development of sustainable communities in which people prosper while using less energy and materials.

This special issue of the *Review* provides in-depth coverage of ORNL's recent efforts to help the government understand and stave off the global warming threat. The Laboratory is analyzing data on various countries' greenhouse emissions and projecting effects on global warming of emission increases as energy use rises and of emissions decreases if restrictions are imposed, as described by Fred Stoss in his article "Managing Global Change Information." Computer models of future climate during global warming are discussed in John Drake's article "Predicting Climate Change."

The question of whether use of biomass fuels as a substitute for fossil fuels could be an effective strategy for reducing net emissions of carbon dioxide to the atmosphere is explored in Janet Cushman, Gregg Marland, and Bernhard Schlamadinger's article "Biomass Fuels, Energy, Carbon, and Global Climate." They suggest that partial use of fast-growing forests for fuel wood to replace coal could reduce atmospheric carbon dioxide concentrations over the long term.

Through partnerships with utilities, the automobile industry, the building industry, and developing countries, the U. S. government hopes to achieve more efficient production and use of energy. Increased efficiency in buildings and transportation should help reduce greenhouse gas emissions to target levels.

ORNL's work in support of these goals is also described in this special issue. In his article "Electric Utilities and Energy Efficiency," Eric Hirst writes about "demand-side management" efforts by electric utilities to influence the amount and timing of customer electricity use, reducing electric bills and carbon dioxide emissions at the same time. In an article on ORNL's research in transportation technology, Jim Pearce et al. explore our efforts in developing clean, safe, efficient, and intelligent transportation vehicles and systems to cut use of fuel, loss of life, and greenhouse gas emissions. In the section "Saving Energy in Buildings and Appliances," Carolyn Krause writes about efforts of ORNL's Buildings Technology Center to improve the energy efficiency of buildings through better roof construction, development of computer software to analyze home energy use and recommend energy efficiency measures and identification and repair of leaks in air ducts that lead to energy losses. Additional articles by Krause and Bill Cabage discuss design and testing of energy-efficient, environmentally friendly refrigerators and heat pumps (including GAX systems and triple-effect chillers).

Internationally, ORNL is playing a role in the U.S. effort to help foreign countries control their greenhouse gas emissions as they increase their production and use of energy. This role is discussed in the article "Promoting International Deployment of Greenhouse Gas Technologies" by Marilyn A. Brown, Julia S. Kelley, and Melissa K. Voss. Also, ORNL is helping developing countries conduct "integrated resource planning" as they increase their production and use of energy to minimize costs and adverse health and environmental impacts. This work is covered in Larry Hill's article "Power to the People: Integrated Resource Planning in Developing Countries."

Today, ORNL's Center for Global Environmental Studies works closely with other Laboratory programs, centers, and divisions to help identify and coordinate the range and depth of the Laboratory's scientific expertise. This is a highly collaborative effort among ORNL organizations that uniquely qualifies the Laboratory to take up the challenges of the U.S. Global Change Research Program. Our interdisciplinary knowledge and skills in the natural, physical, and social sciences are laying the foundation for expanded focused research into the problems of global change. We believe that global change should continue to be a hot area of research. Research results and technology developments described in this issue of the *Review* should enable ORNL to participate in the global change research agenda for the next 20 years.

MICHAEL P. FARRELL is director of ORNL's Center for Global Environmental Studies. ornl

Internationally, ORNL is playing a role in the U.S. effort to help foreign countries control their greenhouse gas emissions.

Predicting Climate Change

By John B. Drake

The global temperature has been about 2 °C warmer than it is at present.

JOHN B. DRAKE, shown here studying a computer simulation of future climate under a global warming scenario, is a mathematician in the Mathematical Sciences Section of ORNL's Computer Science and Mathematics Division. He leads a team that has been developing parallel algorithms for climate modeling and implementing the Community Climate Model-2 of the National Center of Atmospheric Research in Boulder, Colorado, on the Intel Paragon supercomputer at ORNL. ORNL is one of several institutions attempting to predict impacts on climate of greenhouse gases emitted by fossil-fuel combustion and other human activities.

Few scientific topics evoke such general interest and public discussion as climate change. It is a subject that has been highly politicized. New results enter the environmental debate as evidence supporting a position. Usually the qualifiers, the background, and perspective needed to understand the result have been stripped away to form an appropriate sound bite. The attention is understandable given the importance of climate to agriculture and energy use. Fear of global warming and the greenhouse effect has been used as justification for reducing use of fossil fuels and increasing use of nuclear energy and alternative energy sources. It has been suggested that to avoid climate change, a return to a preindustrial level of emissions is necessary.


PCCM2 T42 January
recipitable Water
(kg/m²)
0.3051
61.9859

As a result of the Rio Conference of 1992, representatives of many nations of the world agreed on emission caps that would allow economic growth while still curbing undesirable increases in atmospheric carbon dioxide. As ecological awareness has grown, people want to know the predicted impact of human activities, including fossil-fuel combustion and forest burning, on future climate. Thus, climate prediction through computer modeling has been thrust into the limelight of policy debate.

The subject of this article is not the policy implications of greenhouse warming, or even the validity of the premise that global warming caused by the greenhouse effect is occurring. The subject is the current array of concepts and tools available to understand and predict the earth's climate based on mathematical models of physical processes. These tools for climate simulations include some of the world's most powerful computers, including the Intel Paragon XP/S 150 at ORNL. With these tools, we are attempting to predict the climate changes that may occur 100 years from now for different temperatures of the earth's surface that will likely result from rising levels of carbon dioxide in the atmosphere.

Buried in the layers of Antarctica's ice is a history of the earth.

Facts about Climate

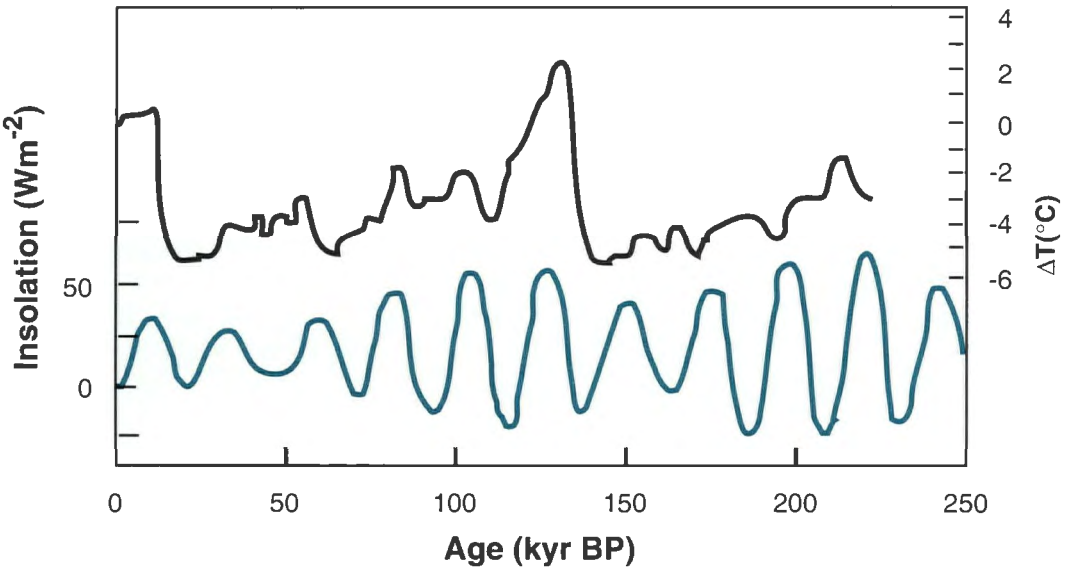
First, consider some of the observational data available about climate. The data help researchers frame the right questions and acquire the best understanding of climate and climate change.

Buried in the layers of Antarctica's ice is a history of the earth as revealing of earth's climate as tree rings are for the environmental conditions during growth of an oak. As ice accumulated from the yearly snowfall, oxygen-18 and deuterium from the atmosphere were trapped and preserved in their proportions to other atmospheric gases and elements. The isotopic fractions of these traces are strongly correlated with the annual mean temperature of the earth's surface. By drilling 2083 meters into the ice at Vostok, Antarctica, in 1987, a collaborating group of scientists from France and the former Soviet Union uncovered the first full glacial-interglacial cycle of earth's temperature.

The data indicate that, over the past 250,000 years when glaciers covered land and then retreated, the earth's temperature oscillated, varying by as much as 11°C (see figure on p. 9). Such data remind us that climate change is a relative concept and that wide variations have occurred in the past. The data tell us that the global temperature has been about 2°C warmer than it is at present and that as little as a 5-degree difference in the global temperature is associated with the ice ages.

Although the climate of the past several centuries has been nearly constant, the longer time scales of the ice core data show that natural cycles may play out over thousands of years. A look at the pattern of temperature oscillations over time invites climate projections, much as fluctuations in the stock market invite some speculators to invest. The temperature record is analogous to the heart's signal in an

A parallel version of the Community Climate Model-2 was developed for ORNL's Intel Paragon XP/S 150 supercomputer to provide answers to energy-related climate questions. For example, what are the effects on climate of 100 years of raising the earth's surface temperature by burning fossil fuels at a rate high enough to double atmospheric CO_2 concentrations? The parallel climate model, as modified at ORNL, can be used to predict climate states resulting from global warming and allow researchers to examine particular quantities such as the precipitable water available in the atmosphere. These fields can be compared with observed data, providing a better understanding of the type and severity of climate impacts. Scientific visualizations of the computed patterns, shown as clouds of varying thicknesses moving over the oceans and continents for each day of a year, have been developed and put on videotape at ORNL (see photograph on p. 7 and on the back cover of this issue).



The Vostok ice core temperature variation in degrees Celsius as a difference from the modern surface-temperature value (top) and solar insolation as a function of time (bottom).

The historical temperature record shows an increase in global average temperature by about 0.5 °C over the past 100 years.

electrocardiogram; in both cases, even the most regular of patterns is punctuated by irregular fluctuations.

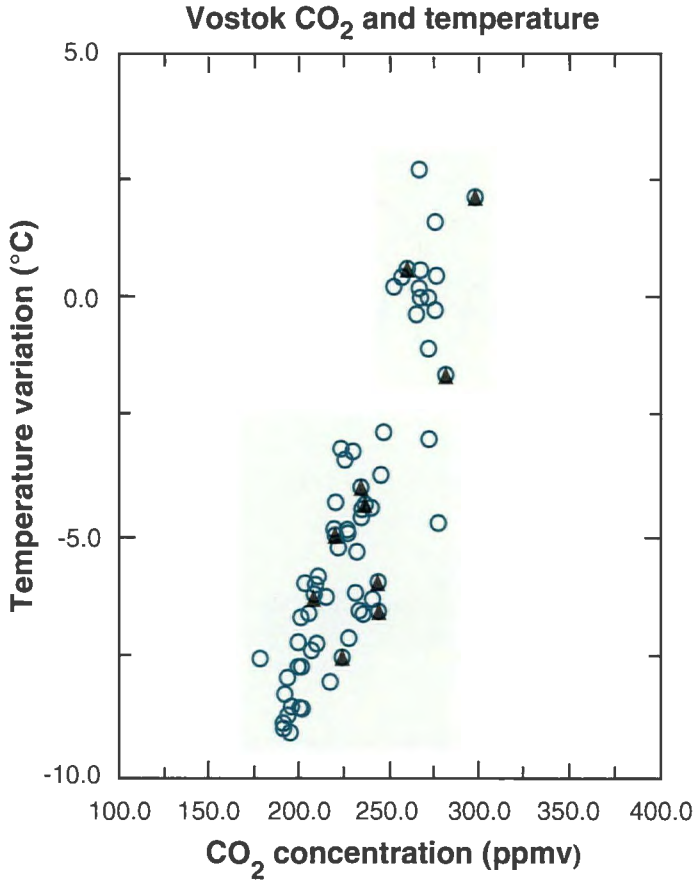
One cycle of the earth's surface temperature is related to the change in the solar input induced by the earth's orbital precession. The precession is the change of the earth's axis of rotation over a 20,000-year period; it is analogous to the "wobble" of a spinning top. The change in temperature induced by orbital precession also has a period of approximately 20 thousand years (kyr).

The data present only a small sample. Only one or two periods of a 100-kyr cycle are apparent, and the current climate is not at a very dependable point for prediction. A longer record might offer the internal consistency required to analyze the structure of the climate time series, but lacking such self-consistent data we must turn to the physical relationships between variables to understand processes that affect climate.

The relationship between the amount of atmospheric carbon dioxide (CO_2) and the earth's surface temperature has been much publicized, although the important graph is rarely seen. The former Soviet scientist M. I. Budyko is credited with first graphing the changes in historical temperature against changes in atmospheric CO_2 concentrations. For the Vostok record this plot is given in the figure on p. 10. The graph suggests a direct, or linear, relationship between the average atmospheric temperature and the amount of CO_2 in the atmosphere—that is, temperature rises as CO_2 concentrations rise. The atmospheric temperature also rises as atmospheric methane increases. However, increases in the amount of dust in the atmosphere are linked to colder climates.

Modern historical data coincide with the beginning of modern weather forecasting, which started with atmospheric pressure measurements following the invention of the barometer in 1644. Temperature, pressure, wind speed and direction, and precipitation measurements have accumulated from an increasing number of sites. The historical temperature record shows an increase in global average temperature by about 0.5°C over the past 100 years. Atmospheric concentrations of CO_2 measured and recorded at the Siple Station in

If a strict linear relationship held between the amount of CO_2 in the atmosphere and the temperature, we should be experiencing a much warmer earth than exists now.



The Vostok ice core temperature variation in degrees Celsius plotted against the atmospheric CO_2 concentration (ppmv).

Antarctica over the same period show an increase from 285 parts per million by volume (ppmv) in 1850 to 312 ppmv in 1953. Measurements made at Mauna Loa (a large volcanic mountain in Hawaii) show that atmospheric concentrations of CO_2 have increased from 315 ppmv in 1958 to 360 ppmv in 1993—the highest atmospheric CO_2 value in the 200-kyr climate record (see asterisk in figure above).

If a strict linear relationship held between the amount of CO_2 in the atmosphere and the temperature, we should be experiencing a much warmer earth than exists now. However, because the current data point does not fall nicely within the time series data, solving the problem of predicting our climate requires a more penetrating look at the climate system.

Global Dynamics: Backbone of the Climate System

The earth's climate system responds primarily to conditions imposed from outside such as the influx of solar radiation. Shortwave radiation from the sun is absorbed only slightly as it travels through the atmosphere. Upon striking the earth's surface—either land, sea, or ice—some of the radiation is reflected as shortwave radiation and some is absorbed, but most is reradiated as long-wave radiation. This long-wave radiation is absorbed more readily than shortwave radiation by the water vapor in the atmosphere or any of a number of other greenhouse gases (mainly, carbon dioxide, methane, and chlorofluorocarbons).

A significant amount of energy is also transferred from the earth's surface in the form of a latent heat flux induced by evaporation or by precipitation. The interaction of the land surface with the atmosphere is strongly influenced by the surface's moisture content. Finally, the energy variation over the earth's surface gives rise to winds and ocean currents that transport the energy.

The energy that accumulates in the warm tropical areas north and south of the equator moves toward the earth's frozen poles. This movement defines the main structure of the atmospheric flow. Together with the salinity of the ocean this poleward flux of energy also drives much of the oceans' circulation. The atmospheric and ocean circulations that control the earth's climate are perhaps the most challenging of fluid

flow problems. Even though such a fluid flow problem can be formulated by classical equations, many mathematical and physical questions arise.

John von Neumann, the brilliant mathematician, physicist, and pioneer of the computer age (as well as a classmate and best friend of ORNL's former research director Eugene Wigner), was fascinated by the climate problem. In 1955, while addressing a conference of early weather modelers, he outlined an approach to climate research. "The approach," he said, "is to try first short-range forecasts, then long-range forecasts of those properties of the circulation that can perpetuate themselves over arbitrarily long periods, and only finally to attempt to forecast medium-long time periods. . . ." Von Neumann separates the time scales of weather and climate, stressing the dependence on the initial data of the weather. However, climate does not depend on particular initial data; rather, it is an inherent behavior of the system that manifests itself only over long time periods, much as the asymptote of a function is approached. He indicates that the hardest problem is in the region between the weather time scale of a few days and the climate scale of years or centuries. This is the region of the "butterfly effect" when the initial conditions (e.g., the fluttering of a butterfly's wings somewhere in Latin America) are seen to influence the specific progression of atmospheric flow.

That there is something worth calling a climate is taken for granted. That the system has asymptotic states has still not been proved mathematically. Von Neumann understood the basic concepts of nonlinear dynamical systems and chaos theory as applied to the atmospheric circulation long before these became subjects in their own right. The current jargon refers to sets in the space of possible weather states, known as attractors. This understanding is evident from his statement, "One generally believes that the various possible initial states which the atmosphere passes through fall somehow into groups, such that each group leads in the long run to the same statistical average. . ." These attractors do just what their name suggests: they attract nearby climate states to ever closer proximity and, if they were really known, would completely characterize climate. Knowing the attractors would be similar to having a topographic map of possible climate states. We would know the dimensions of the valleys into which the states would settle and also how easily the system might pass to another valley.

Although the general fluid flow equations have been known since the time of Leonhard Euler (1707–83), the mathematical theory of existence and the uniqueness of solutions are still developing. Edward Lorenz, a meteorologist at the Massachusetts Institute of Technology, brought the study of chaos to maturity with simple dynamical systems derived from atmospheric dynamics. The discovery of "deterministic chaotic" systems that are analyzable and the development of nonlinear dynamical systems theory have helped expand the notion of what is meant by a solution, of climate itself, and have provided new tools for approaching the equations. These advances stem not from application of a new mathematical theory to the climate problem but from an ongoing interaction among climate scientists, physicists, and mathematicians.

Spatial scales are also important to consider in the climate problem. The fundamental physical processes, "the minutiae of computation" as Von Neumann put it, must be incorporated in some fashion for the small scales to influence correctly the large scales. The interactions of components of the climate system form the backbone of the climate system and follow the routes of energy, mass, and momentum through the atmosphere and ocean. It is, after all, the climate system's job to transfer the energy received in the warmer equatorial regions to the cooler polar regions. As with many jobs, there may be more than one way to do it.

It is...the climate system's job to transfer the energy received in the warmer equatorial regions to the cooler polar regions.

Mathematical Models of the Climate

To enable better understanding of the complex climate system, computer programs have been developed to model interactions of climate components. These general circulation models (GCMs) have been used extensively to understand climatic shifts observed in the past and to try to

Further study at ORNL revealed ways to organize the computation, ...making it possible to implement the climate model on massively parallel computers.

identify possible future responses of the climate system to changing conditions. Can the shifts occur over a short time, such as a decade or century? Will a shift be heralded by phenomena such as an increase in the frequency of El Niños and their surge of warm, western Pacific Ocean water toward South America? What are the different mechanisms of poleward heat transport that might provide the backbone of other climate states? These questions, and many others, indicate the complexity of current climate studies. Simple cause-and-effect arguments are usually not effective explanations in this arena. Complex computer models are practically the only tools available, so they are typically used to justify statements about climate and global dynamics.

For 20 years, climate-modeling researchers have been using some version of the Community Climate Model (CCM1) of the National Center for Atmospheric Research (NCAR). CCM1, which was produced in 1987, was operated on large serial supercomputers. Now, many of these researchers are using CCM2—a step forward that has been characterized as moving from some other planet to the earth. This step roughly corresponds with the advent of large, shared memory, parallel, vector computers such as the Cray YMP. Parallel computers allow a more detailed modeling of climate. The detailed examination of the balance of physical processes in the models moves closer to the observed state as modeling of details increases, building confidence that the physics is being captured.

Current atmospheric climate models capture very well the qualitative structure of the global circulation. The transport of energy from the warm equatorial regions to the cold poles and the split of the associated winds into cells are reproduced in simulations both qualitatively and quantitatively. The tropical Hadley cell and the mid-latitude Ferrel cells and jet streams are in good agreement with observations. These are the basic structures of the atmospheric circulation felt on the earth's surface as the doldrums, trade winds, mid-latitude westerlies, and polar highs.

The ability of the models to reproduce the current climate builds confidence in their physical validity. This validation, however, is not license to use the models for future climate predictions. Another important justification for use of the models has been their application to past climatic regimes. The NCAR CCM has been used to simulate climate effects resulting from increases in solar radiation in the northern summer because of changes in the earth's orbit. One of the effects was warmer land temperatures that gave rise to more intense monsoons. Increases or decreases in solar radiation resulting from changes in the earth's orbit are believed to be responsible for conditions that produced climates of past ages. According to Stephen Schneider of NCAR, "The ability of computer models to reproduce regional climatic responses to the changes in solar radiation brought about by variations in the earth's orbit lends a major element of confidence to the reliability of these models as forecasting tools for the future climate resulting from increasing greenhouse gases."

CCM2, the most recent code in a series of climate models developed by NCAR, captures the intricate interactions of the physical processes outlined here. This climate model, which is available to academic and industrial research users, simulates the time-dependent response of the climate system to the daily and seasonal variation of the solar input and of sea surface temperatures. For the past 10 years and into the foreseeable future, these models form the basis of a broad range of climate research and scenario testing used in support of decision makers who formulate national energy and environmental policies.

Parallel Computing Used with Global Circulation Models

Advances in computer technology have been welcomed by climate researchers because long climate simulations can take months of computing time to complete. The latest generation of supercomputers is based on the idea of parallelism. The Intel Paragon XP/S 150 can solve a single complex problem using the combined

speed of 2048 processors. This computer differs from other supercomputers in that the memory of each processor is not accessible by the other processors. Such a system is called a distributed memory computer rather than a shared memory computer. This computer design allows for massive parallelism to be applied to problems but complicates formulation of the calculations.

The CCM2 is used almost exclusively on parallel supercomputers. The large computational requirements and the heavy volume of output generated by the model exclude its effective use on workstation-class systems. The heart of the dynamics algorithm in the CCM2 is based on spherical harmonics, the favorite functions of mathematicians and physicists who must represent functions with values on the surface of a sphere. The method transforms data on the sphere into a compact, accurate representation. Data for a 128 × 64 point grid on the earth's surface could be represented with only 882 numbers (coefficient) instead of 8192. It has had a very long reign as the method of choice for weather and climate models because of the accuracy of the spherical harmonic representation and the efficiency of the methods used to compute the transform. The transform is a "global" method in the sense that it requires data from the entire globe to compute a single harmonic coefficient. For distributed memory parallel computers, these calculations require communication among all the processors. Because communication is expensive on a parallel computer, many thought that the transform method had seen its day.

Before ORNL researchers became involved, parallelism in the models was limited to a shared memory paradigm in which only a few—1 to 16—processors were used. Because of the global communication required for the spectral transform, the distributed-memory parallel computers did not look promising. However, further study at ORNL revealed ways to organize the computation, completely changing our view and making it possible to implement the CCM2 on massively parallel computers.

Our research identified several parallel algorithms that keep the transform method competitive, even when using large numbers of processors as on the Intel Paragon XP/S 150 at ORNL. This powerful machine has 1024 node boards, each having two computational processors and a communication processor. The full CCM2 climate model was implemented for this parallel computer by a collaboration of researchers from ORNL, Argonne National Laboratory, and NCAR. It is currently being used by ORNL's Computer Science and Mathematics Division as the basis for the development of a coupled ocean-atmosphere climate model under the sponsorship of the Department of Energy's Office of Health and Environmental Research.

With the increase in computing capacity offered by the new generation of parallel computers, many researchers are working to improve the models by coupling the ocean and atmosphere. This exciting advance in the models brings us a step closer to a comprehensive model of the climate system. With this type of integrated model, a number of areas of climate study will open up. First, an improved method will emerge to simulate the earth's carbon cycle. Ocean and land processes (e.g., forests and soils) act as sources of and sinks for carbon in the atmosphere. Second, inclusion of high-resolution, eddy-resolving ocean models with atmospheric models will allow scientists to address previously unapproachable questions of the climate's predictability. The models will exhibit the typical behaviors of the interaction of the ocean and the atmosphere. The El Niño is but one mode of interaction. Discovering and identifying these modes may hold the key to the question of the climate's predictability.

Our models could be used to predict the overall impact on climate of counteracting atmospheric effects from both manmade and natural emissions—the warming effects of greenhouse gases and the cooling effects of sulfate aerosols. By using the increased computing power of the Intel Paragon, the IBM SP2, or the Cray Research T3D, researchers should advance one step further in understanding the complex interrelations among natural processes, human activities such as fossil fuel combustion, and the climate of our terrestrial home. **ornl**

With the increase in computing capacity offered by the new generation of parallel computers, many researchers are working to improve climate models.

Biomass Fuels, Energy, Carbon, and Global Climate Change

By Janet Cushman, Gregg Marland, and Bernhard Schlamadinger

There is widespread concern that observed increases in the concentration of carbon dioxide and other greenhouse gases in the earth's atmosphere will ultimately lead to changes in the earth's climate. Although it is clear that the atmospheric concentration of carbon dioxide is increasing and that the increase is being driven in large measure by the burning of fossil fuels (coal, oil, and natural gas), the climatic consequences of increasing atmospheric carbon dioxide are not so clear. Recognizing that fossil fuels play a very important role in the economies and lifestyles of people throughout the world, and acknowledging that great uncertainty exists regarding the climatic consequences of burning fossil fuels, it is reasonable to ask if the global economy can be powered in ways that might have less impact on the environment because they discharge less carbon dioxide.

Oak Ridge National Laboratory has long been involved in research on alternative energy systems. Much of this research, including the Department of Energy's Biofuels Feedstock Development Program in ORNL's Environmental Sciences Division, began as efforts to develop domestic sources of clean, inexpensive energy. Biomass fuels used in efficient ways might provide a sustainable source of such energy. Researchers in the Biofuels Feedstock Development Program are now studying the environmental and economic issues that stem from biomass production and use as well as developing efficient new biomass energy crops and cropping systems.

Janet Cushman and Gregg Marland examine the cross section of a tree, which began sequestering carbon from the atmosphere in 1648. Despite being harvested in 1972, some portions of this tree continue to store carbon in wood products.

Carbon Storage vs Energy Use

The potential role of biomass energy acquired a new dimension when it was suggested that planting large areas of new forest could slow the increase in

Bernhard Schlamadinger

atmospheric carbon dioxide by removing carbon dioxide from the atmosphere. Two questions then arose: How does using trees to remove carbon dioxide from the atmosphere compare with using biomass as a fuel, and how do these possibilities compare with harvesting forests for conventional wood products?

There are two common, but mutually exclusive, impressions about biomass fuels and carbon dioxide. One first impression is that biomass fuels and fossil fuels are not different because, when burned, both yield carbon dioxide. This is true if land from which biomass is harvested for fuel is not replanted and instead is converted to other uses. However, if the biomass is produced sustainably, the growing trees and other plants remove carbon dioxide from the atmosphere during photosynthesis and store the carbon in plant structures. When the biomass is burned, the carbon released back to the atmosphere will be recycled into the next generation of growing plants (see the figure on p. 18). When biomass is used for fuel in place of fossil fuels, the carbon in the displaced fossil fuel remains in the ground rather than being discharged to the atmosphere as carbon dioxide. The productivity, or rate of growth of the trees, becomes an important consideration. While slow-growing trees can take a very long time before the released carbon is recaptured in the next generation of trees, fast-growing trees can recycle carbon rapidly and will displace fossil-fuel use with every cycle.

A second impression is that biomass energy systems, because they recycle carbon, produce no net emissions of carbon dioxide. This is not strictly true either. It takes some energy, much of it now provided by fossil fuels, to grow and harvest biomass fuel crops and to haul the fuel to

Fast-growing trees can recycle carbon rapidly and will displace fossil-fuel use.

Wood chips from fast-growing trees are stored in Hawaii. These chips will later be used as fuel.

ORNL scientists examine whether substituting biomass fuels for fossil fuels could cut emissions of CO_2.

a power plant. The use of biomass fuels does result in some discharge of carbon dioxide. The extent to which biomass fuels can displace net emissions of carbon dioxide will depend on the efficiency with which they can be produced and used.

Forests that are not harvested do not continue to accumulate carbon indefinitely. They eventually approach maturity and achieve, over time, a balance between the carbon taken up in photosynthesis and the carbon released back to the atmosphere from respiration, oxidation of dead organic matter, and fires and pests. If fossil fuels continue to be used to meet society's energy needs, reforestation or afforestation of ever larger areas would be needed to prevent increasing concentrations of atmospheric carbon dioxide. Does it make more sense to use trees for energy and to recycle carbon than to store carbon in forests while continuing to burn fossil fuels? Although the system is complex and critical variables are different in different places, it is important to understand the choices available.

Land Use and Carbon Dioxide

Scientists at ORNL have begun to examine a variety of land management alternatives, including whether substituting biomass fuels for fossil fuels could be an effective strategy for reducing net emissions of carbon dioxide to the atmosphere. How can limited resources of land be used most effectively to minimize net emissions of carbon dioxide to the atmosphere while meeting the energy requirements of our global society? Should we preserve existing forests, plant new forests, or develop biomass-based energy systems, or should we encourage the use of long-

lived wood products? Is there some other or mixed strategy that is most attractive for minimizing the net emissions of carbon dioxide?

In this discussion we focus on minimizing the risk of global climate change through minimizing carbon dioxide emissions, but we recognize that other criteria go into land-use decisions. Many of these are being evaluated in other portions of ORNL's assessment of biomass energy resources and opportunities. For example, in some regions of the world, deforestation is a major source of carbon dioxide emissions. Currently, an estimated 15 to 20% of atmospheric carbon dioxide emitted by human activities results from deforestation or, more generally, from changes in land use. Clearly, many motivations, including the need for food production, are involved in decisions on land use and will affect the amount of land available for reforestation or for biomass energy crops. Although we are considering the possibility of planting new areas of forest, the rate of growth in atmospheric carbon dioxide could also be reduced substantially by decreasing the current rate at which forest is being converted to other land uses. Coincidentally, the amount of carbon dioxide emitted annually from deforestation around the world is of the same order of magnitude as the amount of additional carbon dioxide that would be discharged if the 14% of primary energy now supplied by biomass fuels globally were instead supplied by oil and coal.

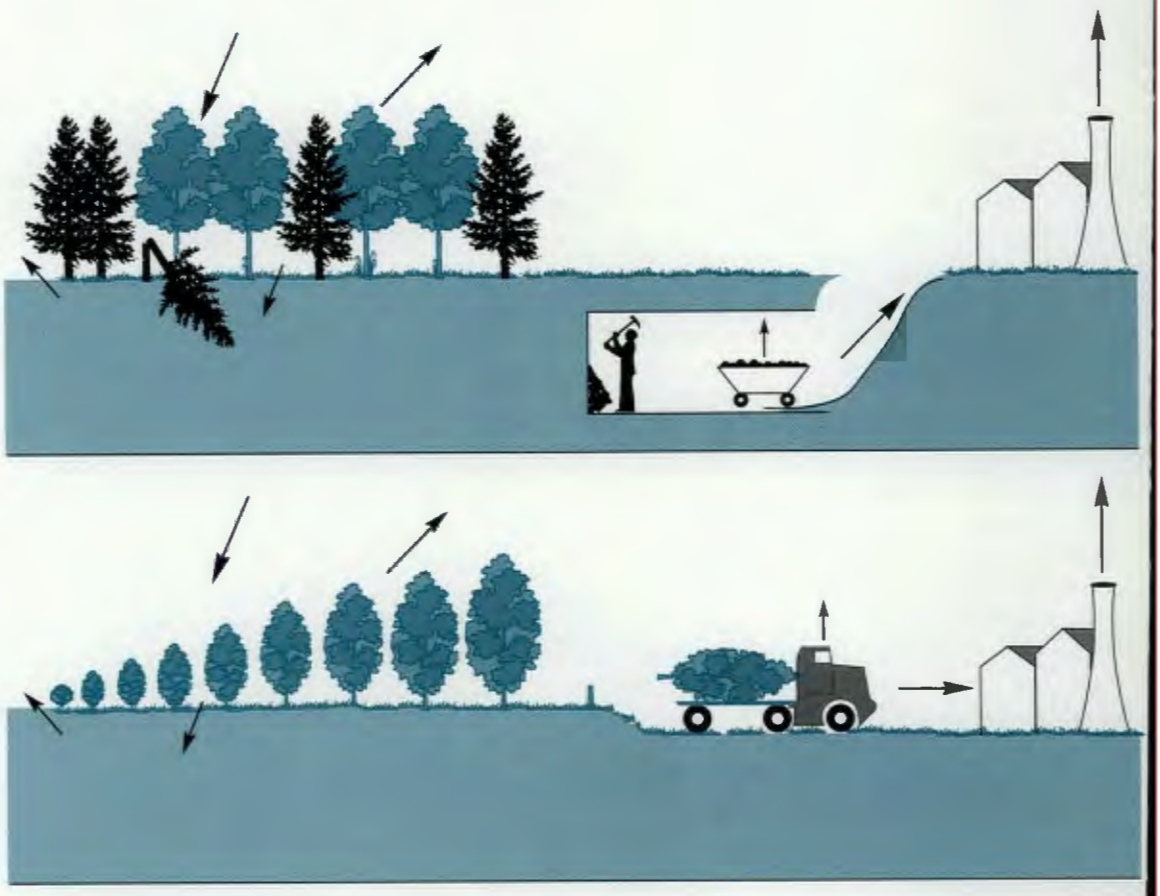
The net impact of land management and the use of biomass-based products on the cycling of carbon will depend on the type of land used, the management practices used on that land, how the biomass products are used, and the time frame of the analysis. Especially important are how much carbon is stored on the land (including in trees and other plants and in the soil and plant litter on the ground) at the beginning and end of the analysis, how much fossil-fuel use is displaced, how much carbon is stored in durable wood products, and how much energy is required for forest and other land-management operations. Also important are how efficiently forest and other biomass products are used and the alternate products for which they substitute, including whether biomass fuels are substituted for coal, oil, or natural gas; whether they are used to produce liquid fuels, heat, electric power, or some combination of these; and the efficiency with which they are used. The net impact on carbon cycling will depend on the mix of forest and other biomass products used for short-lived products like paper, long-lived products like construction lumber, and fuels. It will depend on whether the lumber displaces aluminum, concrete, glass, or plastic. It will depend ultimately on whether the waste products are reused, buried in landfills, burned for energy, or incinerated.

Although we have focused on trees and forest products in our analyses to date, the most advantageous land use for confronting the carbon balance may not necessarily involve trees. If the primary intent is to store carbon on site, the obvious choice is a high-density forest. On the other hand, if production of biomass energy is the goal, a fast-growing herbaceous crop such as switch grass may be the best choice for some biomass energy technologies and some types of land. Under other circumstances, wood, biodiesel, or another fuel may be able to displace the most fossil fuel. And, if we broaden consideration to include other biomass products, we may find other alternatives. It is important to examine the full range of the affected system and to see how the carbon balance is affected.

The extent to which biomass fuels can displace net emissions of carbon dioxide will depend on the efficiency with which they can be produced and used.

Modeling Carbon Flows

To illustrate the impacts of some land-management alternatives on net carbon emissions, we use a simple mathematical model to compare two scenarios. In the first scenario (top half of the figure on p. 18) 1 hectare of land is used to grow trees to store carbon for 50 years. During this period, a coal-fired power plant is used to generate electricity. In the second scenario (bottom half of the figure), the trees are harvested each time they reach an appropriate size and are used to displace some of the coal that would otherwise be burned. At the end of 50 years, there will be more carbon stored in living trees in the first scenario, but there will also have been more coal burned than in the second scenario. The net



The rate of accumulation of carbon in the forest and the amount of coal displaced depend on the growth rate of the trees.

Top: Growing forest accumulates carbon until it achieves, over time, a balance between the carbon taken up in photosynthesis and the carbon released back to the atmosphere from respiration, oxidation of dead organic matter, and fires and pests. In the meantime, fossil fuels are used to meet society's energy needs. Bottom: In productive forests, trees can be harvested for use in producing heat or power. Although harvesting may result in less carbon stored in standing biomass and forest soils, biomass fuels replace some of the fossil fuel that would otherwise be burned. The carbon in that fossil fuel remains stored in the ground rather than being released to the atmosphere. In both scenarios there are some energy needs for gathering the resource and converting it into useful energy, but, as the arrows on the transportation system suggest here, these are generally comparatively small. Arrows provide a qualitative indication of the magnitude and direction of carbon flows.

difference in carbon dioxide added to the atmosphere depends on how fast the trees grow and how efficiently they are harvested and converted into useful energy. The net carbon balance also depends on the amount of biomass on the land at the beginning of the analysis. If, for example, the land were already occupied by mature forest, carbon would continue to be stored but little or no additional carbon would be accumulated. On the other hand, unforested land could have a very large capacity to accumulate additional carbon in trees. Both the rate of accumulation of carbon in the forest (scenario 1) and the amount of coal displaced

(scenario 2) depend on the growth rate of the trees.

By comparing the results of these and other scenarios under a variety of initial conditions, biomass growth rates, and end uses, we begin to get some clues to the most carbon-efficient ways to manage forest or other lands and to the potential for biomass fuels to mitigate the increase in atmospheric carbon dioxide. The comparisons show that when the amount of forest biomass on the land in the beginning is very large and the productivity of the land is low, the most effective strategy is to allow the trees to grow, to stand, and to store carbon. In other words, slow-growing old-growth forests are best left in place. Similarly, the net carbon balance on degraded lands with low productivity is best when they are reforested, without harvesting, to store carbon.

Results are quite different on lands that can support high growth rates. There, the net reduction in carbon dioxide emissions is far greater if the trees are harvested and used as a fuel, with prompt replanting, than if the trees are left unharvested for carbon storage. On such lands, several generations of fast-growing trees (such as poplars) can be harvested in 50 years, displacing additional fossil fuel with each harvest. There are also intermediate productivities where the choices are not so clear-cut and the sign of the net carbon balance depends on other variables such as the efficiency with which biomass is substituted for fossil fuels.

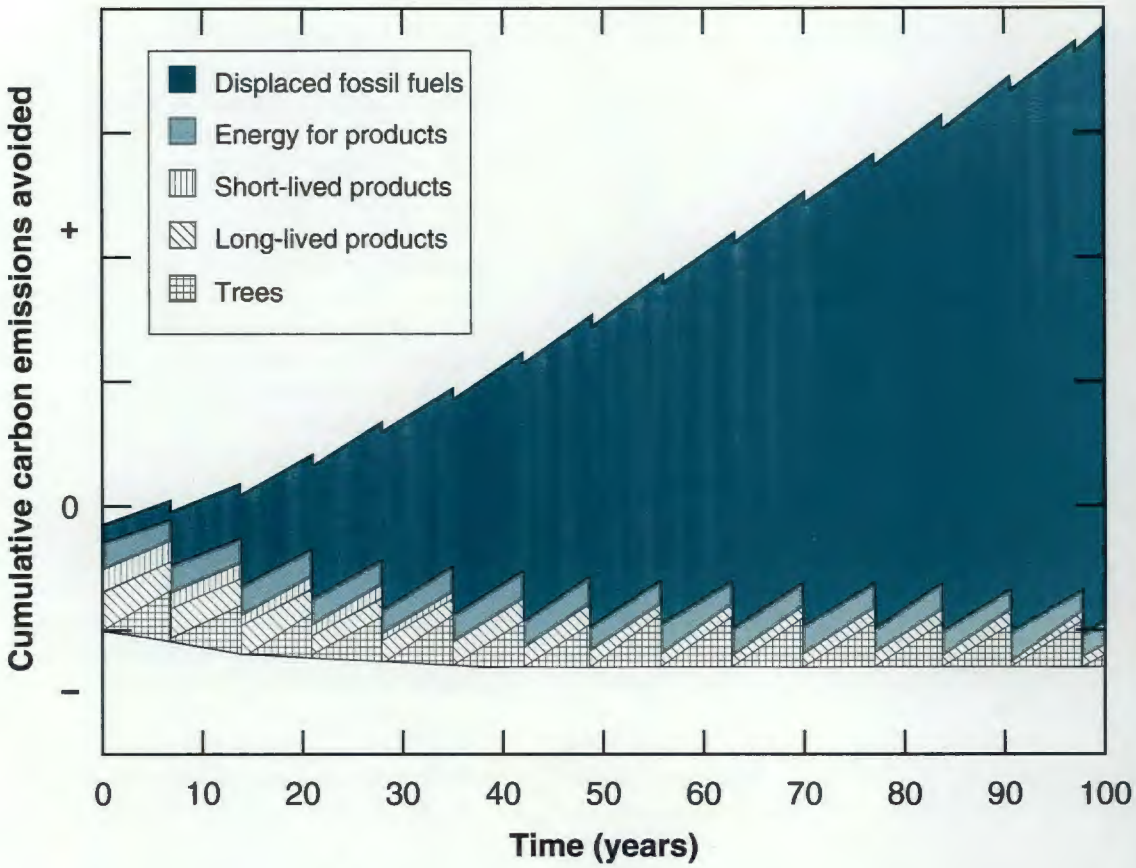
Using current technologies, the most efficient way to convert biomass to useful energy, and thus to maximize the carbon dioxide savings, is to burn the biomass for heat or electricity generation, displacing coal. In all scenarios, carbon dioxide benefits increase as biomass growth rates increase and as utilization efficiency increases. The Biofuels Feedstock Development Program at ORNL aims to increase the productivity of tree and grass crops and improve the efficiency of biomass feedstock supply systems. Improvements in these areas offer a large payback both in the economics of biomass fuels and in the potential for net reductions in carbon dioxide emissions.

A more comprehensive model of carbon flows is now being developed at Joanneum Research in Graz, Austria, in collaboration with ORNL. This spreadsheet model allows us to calculate the carbon balance of land management and biomass utilization strategies. It can consider different types of biomass fuels as well as other biomass-based products from forestry or agriculture. Input parameters for the model describe the growth rate, rotation length, management intensity, previous land use, carbon dynamics of the soil and litter, fate and life expectancy of the harvested products, efficiency of fossil-fuel substitution, and energy required for land management. Model output is shown in diagrams with time on the horizontal axis and cumulative net reduction in carbon emissions on the vertical axis.

To illustrate the variety of factors that come into consideration, the figure on p. 20 shows model results for a scenario in which a forest is harvested for a conventional mix of long- and short-lived products and energy and is then replanted for production of fuel wood. This scenario assumes high forest productivity and high efficiency in use of the fuel wood. Note that the carbon in wood products is gradually released to the atmosphere over time as the products decay. Some carbon is lost from soils (reflected in the drop in the bottom line of the figure) as the forest is converted to shorter rotations with more frequent harvests. Most strikingly, the net savings of carbon emissions continues to build over time as coal consumption is displaced.

Much remains to be learned about the potential for producing and using biomass fuels to reduce carbon emissions. However, initial studies of the carbon balance suggest that biomass fuels could play a significant role in minimizing net emissions of carbon dioxide to the atmosphere. And, very importantly, the initial studies suggest that the optimal strategy will be different from place to place, determined by the quality of the land, its current uses, competing uses, and the demands for energy and other products. Continuing studies at ORNL and at Joanneum Research will explore the potential of biomass fuels as a strategy for confronting global climate change. ornl

Several generations of fast-growing trees can be harvested in 50 years, displacing additional fossil fuel with each harvest.



When a productive forest is harvested and the site replanted with energy crops, the initial harvest will yield some long-lived products, some short-lived products, and some energy products. Over time, the various products will gradually decay and release their carbon to the atmosphere and some carbon will be lost from the soil because of more intensive management. The energy products harvested periodically over time will displace fossil fuels, allowing them to be left in the ground. There will also be some fossil fuels left unburned because wood products typically require less energy for their production than do other materials for which they substitute. The cumulative reduction in carbon emissions over time will depend on the rate of energy-crop growth, the efficiency of biomass substitution for fossil fuels, and many other parameters being modeled in studies at ORNL and Joanneum Research. The carbon balance would look much different (better) if this scenario were implemented on surplus agricultural land because we would expect a buildup of soil carbon and no loss of carbon to the atmosphere as wood products are oxidized over time.

BIOGRAPHICAL Sketches

JANET CUSHMAN is project manager for the U.S. Department of Energy's Biofuels Feedstock Development Program at Oak Ridge National Laboratory. A staff scientist in ORNL's Environmental Sciences Division, she has been associated with ORNL's biofuels research since 1980, serving as a task manager in the Short Rotation Woody Crops Program, project manager for the Herbaceous Energy Crops Program, and deputy project manager for the Terrestrial Energy Crops Program. She holds a B.A. degree in biology from Hiram College and an M.S. degree in ecology and evolution from Yale University.

GREGG MARLAND is a senior staff scientist in ORNL's Environmental Sciences Division. He has a Ph.D. degree in geology from the University of Minnesota. Before coming to ORNL in 1987, he worked on net-energy analysis and carbon dioxide research at the Institute for Energy Analysis, Oak Ridge Associated Universities.

BERNARD SCHLAMADINGER is a scientific staff member at Joanneum Research, Institute for Energy Research, in Graz, Austria. He has an advanced degree in mechanical engineering and economics from Graz University of Technology. He spent six months at ORNL on a sabbatical during 1994.

Global Change Research Highlights

By Carolyn Krause

Wood—the fuel source of the past—is expected to be a fuel source of the future.

Marker Found for Gender of Biofuel Tree

Wood—the fuel source of the past—is expected to be a fuel source of the future. Fast-growing trees are being cloned and nurtured for conversion to biofuels to replace or supplement gasoline for transportation.

The future may also bring higher temperatures and drought if global climate changes as predicted. So, it seems practical to raise fast-growing trees that not only provide fuel by capturing carbon from the atmosphere (helping to deter climate change) but also flourish under dry conditions.

A recent ORNL finding has bearing on this goal. Hybrid willow trees have been cloned because they grow fast and serve as good fuel sources. However, there are important gender differences. Male willow clones are generally more tolerant of drought than female willows. Also, male willows cause no weed problems because they do not disperse seeds.

It's not easy to tell a male willow from a female willow because each tree does not express its gender identity until it is 6 to 20 years old. However, Jerry Tuskan and Greg Roberts, researchers in ORNL's Environmental Sciences Division, in collaboration with Swedish scientists through the International Energy Agency, have found a potentially useful method for early gender identification in willows.

"We have identified a DNA marker for gender determination in hybrid willow trees," Tuskan says. "The marker is present in all female hybrid willow and absent in all males."

The marker will ultimately be used to isolate and characterize the DNA sequence responsible for gender selection. Use of this DNA sequence should greatly increase researchers' ability to

Gerald Tuskan uses genetic engineering techniques to determine the gender of a hybrid willow tree in an early stage of development.

Interior of a plantation of Swedish willow trees at the State University of New York in Syracuse.

The ORNL researchers found an increase in growth efficiency in the yellow poplars.

identify highly productive drought-resistant trees for biofuels.

Tree Growth in an Atmosphere Enriched in Carbon Dioxide

One of the longest studies of a forest tree species in an atmosphere enriched in carbon dioxide (CO_2) suggests that in this environment trees absorb airborne carbon more efficiently and that some of the absorbed carbon ends up being stored in soil around tree roots. The ORNL study examined the response of trees to additional atmospheric CO_2 from increased energy production using fossil fuels. Elevated CO_2 levels may cause global warming and possibly disruptive climate change.

This study addresses a variety of questions. How do forest trees respond to rising concentrations of atmospheric CO_2 from increased fossil fuel combustion, forest burning, and other sources? Do they grow faster? Do their trunks and branches become larger than normal? Are their leaves larger or smaller? Do they grow more efficiently even when deprived of nutrients and water? Will their response to elevated levels of atmospheric CO_2 be to absorb and store more carbon from the atmosphere, slowing global warming?

To help address these questions, ORNL has been conducting a series of long-term studies of a forest tree species in a CO_2-enriched atmosphere. The results of the study, which is sponsored by DOE's Global Change Research Program, were first reported in a letter to the May 28, 1992, issue of *Nature* by researchers in ORNL's Environmental Sciences Division. They are Richard J. Norby, Carla A. Gunderson, Stan D. Wullschleger, Elizabeth G. O'Neill, and Mary K. McCracken. The letter, entitled "Productivity and compensatory responses of yellow-poplar trees in elevated CO_2," was the third most cited 1992 scientific paper in ecology and environmental sciences, according to the January 1995 issue of *Science Watch*.

ORNL studies of yellow poplar tree responses to an atmosphere enriched in CO_2 have not found the dramatic growth seen in some studies with potted tree seedlings or irrigated and fertilized saplings—the so-called CO_2 fertilization effect. The ORNL researchers found an increase in growth efficiency—the amount of stem wood produced per unit leaf area—in the yellow poplars. They observed a doubling of leaf photosynthesis—the use of sunlight to produce carbohydrates that provide energy for tree growth. However, the relative amount of leaf area that was produced was less, and the overall stem mass—

the girth of trunk and branches—remained about the same. The additional carbon that was absorbed resulted in increased production of fine roots, rather than wood.

The increased fine-root production, Norby says, suggests that some of the additional carbon in the atmosphere may be eventually absorbed and stored in the soil rather than in trees. Fine roots, he adds, die and decay rapidly, but their residue is an important source of the carbon in soil. The possibility of increased carbon storage in soil is an important focus of DOE's new Terrestrial Carbon Processes Program, which aims at identifying and quantifying natural mechanisms of the terrestrial ecosystems that may affect trends in atmospheric CO_2 concentration. Program scientists will develop the scientific understanding needed to model, predict, and quantify the role of terrestrial ecosystems in regulating the balance of global carbon.

"Our results suggested strongly that, because less leaf area is needed to sustain the same growth rate and because fine-root production increased, the yellow poplar trees grow more efficiently in a CO_2-enriched atmosphere," Norby says. "The increased productivity showed up as additional fine roots rather than in wood.

"The increased efficiency implies that these trees may be better able to withstand environmental stresses, such as drought, and survive even when nutrients are limited. Thus, they may last longer as a natural resource for removing carbon from the atmosphere and storing it."

The interaction of elevated CO_2 with the stresses associated with predicted increases in air temperature is the current focus of the ORNL research group.

The results of the ORNL paper are sometimes incorrectly cited as evidence that trees will not grow bigger and faster in a CO_2-enriched atmosphere unless they are provided with additional nutrients, including fertilizing pollutants such as sulfates and nitrates from acid rain.

These trees may be better able to withstand environmental stresses, such as drought, and survive even when nutrients are limited.

ORNL scientists examine the response of yellow poplar and white oak trees grown in chambers whose atmosphere is enriched in carbon dioxide. They found increased productivity that showed up as additional fine roots rather than in wood.

"That this interpretation is wrong is shown by the large response of white oak trees to elevated carbon dioxide levels at the same experimental site at ORNL," Norby says. "Both species increased their growth efficiency despite a deficiency of nutrients at the site. When our results were corrected for short-term experimental influences on leaf area, we found that both white oak and yellow poplar trees showed about a 35% increase in productivity in elevated carbon dioxide. These results suggest a potential increase in forest capture of carbon even when nutrients are limited."

The new ORNL study is the first to determine that ozone retards mature tree growth in a real forest environment.

Ozone and Climate Change May Stunt Tree Growth

ORNL scientists have found that ground-level ozone in the environment can reduce the growth of the loblolly pine, a forest tree species of great economic importance in the Southeast. Their findings suggest that significant reduction in forest tree growth could result from exposure to ozone combined with the higher temperatures and drought of predicted global climate change.

The scientists reported the results of their 5-year study of 28 mature trees on the Oak Ridge Reservation in a March 1995 issue of the journal *Nature*. Authors of the article "Interactive effects of ambient ozone and climate measured on growth of mature forest trees" are S. B. (Sandy) McLaughlin, an ecologist in ORNL's Environmental Sciences Division, and Darryl J. Downing, a statistician in the Computing and Mathematical Sciences Division. Together they used statistical techniques to separate the effects of ozone from other factors. An article on the work also appeared in the March 21, 1995, issue of the *New York Times*.

Ground-level ozone forms when hydrocarbons and nitrogen oxides in the air react in the presence of sunlight. Sources of these chemicals include emissions from vegetation, fossil-fuel power plants, and highway vehicles.

In the 1980s, declines in growth of loblolly pine trees in the Southeast were observed. This decrease aroused concern because loblolly pine is an important component of southern pine forests. Logging of southern pine forests, which cover an estimated 60 million acres, contributes $4.5 billion to the regional economy annually.

Air pollution was suspected as a cause of the forest decline. Studies of tree seedlings exposed to ozone in closed chambers at ORNL and elsewhere showed that the pollutant stunted seedling growth. The new ORNL study is the first to determine that ozone retards mature tree growth in a real forest environment.

The growth of the trunk of each tree in the experiment was monitored over 5 years using a dendrometer. This instrument consists of a metal band positioned around the stem that precisely measures fluctuations in the stem's rate of expansion.

"When ozone levels in the air remained about 40 parts per billion, as happens almost every day in the eastern United States, tree growth was reduced," McLaughlin says. "The decline was more pronounced under drying conditions. When ozone levels were especially high, we found that the stems actually contracted as water became very limited. Ozone seems to multiply the adverse effect on trees of lack of moisture."

Evidence from other studies, McLaughlin notes, suggests that tree exposure to ozone can lead to increased water losses through foliage and lower uptake of water (because of reduced root growth). As a result, ozone may impair a tree's ability to efficiently use water available for growth.

Thanks to a wide range of temperature, rainfall, and other weather conditions, the scientists were able to measure differences in growth reduction for periods of both high and low moisture. In 1988, the driest year of the study, high ambient ozone levels reduced tree growth by an average of 13%. In the wettest years, 1989 and 1992, little growth reduction occurred. The average growth reduction attributed to ozone for 5 years was 5%.

"Predicted results of future climate change from some computer models," McLaughlin says, "include periods of increasing temperatures and drought. Our results suggest that trees exposed to ozone under these climatic conditions would experience more significant growth reductions."

Studies at ORNL by Rich Norby and others have shown that elevated levels of atmospheric carbon dioxide may increase productivity of yellow poplar and white oak trees, at least in terms of increased root growth. But if the levels of this greenhouse gas are high enough to cause significant warming of the climate and drought, the McLaughlin-Downing study of loblolly pines suggests that overall growth rates of some trees may be reduced, not increased, because regional ozone levels are also projected to increase. Of course, ORNL scientists note, these studies must be repeated for other species of trees, under various conditions such as reduced availability of water and nutrients, to better understand the detailed effects on trees of elevated levels of carbon dioxide and ozone.

Forests and Changes in Precipitation

It is predicted that global warming could lead to changes in regional precipitation, even periods of drought. How would climate change affect the growth of forest trees?

To answer this question, scientists in ORNL's Environmental Sciences Division are conducting a precipitation experiment in a forest on DOE's Oak Ridge Reservation.

In this "throughfall displacement experiment" conducted at the Walker Branch Watershed on DOE's Oak Ridge Reservation, trees in various plots of a predominantly oak forest receive different amounts of soil moisture from rain and snow. One-third of the precipitation falling through the trees is intercepted by troughs, preventing the water from reaching the soil. The captured water flows by gravity from the "dry" treatment area to the "wet" treatment area, where it provides additional moisture to the soil. This project is believed to be the world's largest experimental manipulation of an oak forest (which also has maple and dogwood trees).

"We found that the experimental system can produce statistically significant differences in soil water content in years having both extremely dry and extremely wet conditions," says Paul J. Hanson, an ESD project researcher. "The experimental design produces soil water changes without affecting temperatures of the soil and forest floor."

Project researchers had predicted that oak trees would be more resistant to drought than maples for two reasons: oaks have longer roots that can reach deep water supplies, and oaks maintain or accumulate high concentrations of water-soluble compounds in leaves, making them more drought tolerant.

"Large differences in drought tolerance were observed between dogwoods and chestnut oaks even in the first year of the study with above normal rainfall," says Timothy J. Tschaplinski, another project researcher. "The oaks were better able to withstand dry conditions.

"Such differences might ultimately lead to altered species composition in the Southeast's deciduous forests if climate changes occur."

After almost two years of the experiment, the researchers found no differences in growth responses for mature oaks and maples. However, in the forest undergrowth the leaves and stems of maple and dogwood saplings were found to grow 45% faster in wet areas than in dry ones.

"Our goal," says Hanson, "is to understand how climate change that may result from increasing emissions of greenhouse gases will affect forests. In this way, we will be able to better assess the impacts of greenhouse gas emissions."

Large differences in drought tolerance were observed between dogwoods and chestnut oaks.

Geologic Record Reveals Atmospheric CO_2 Changes

Some 7000 to 9000 years ago, vegetation in the Chihuahuan Desert in New Mexico shifted from mostly grass to mostly shrubs. Evidence for this vegetation shift comes from a study of isotope ratios in the geologic record by geochemist David Cole of ORNL's Chemical and Analytical Sciences Division and H. Curtis Monger of New Mexico State University in Las Cruces.

What was the dominant cause of this shift? Climate change, increases in atmospheric carbon dioxide, or a combination?

Paul Hanson checks the plastic troughs used in ORNL's "throughfall displacement experiment" at the Walker Branch Watershed on DOE's Oak Ridge Reservation.

Aerial view of the troughs near ORNL used to ensure that trees in various plots of a predominantly oak forest receive different amounts of soil moisture from rain and snow.

"Studies of Antarctic ice cores indicate that atmospheric carbon dioxide increased rapidly during this period," Cole says. "Also, evidence for changes in temperature and dryness are recorded in pack rat remains and in reconstruction of the earth's surface features, such as ancient lakes."

To help determine the dominant cause of the vegetation shift, the researchers measured the ratios of isotopes in the desert's soils. In a letter published in the April 7, 1994, issue of *Nature*, they report that the isotopic signature in the geologic record pins the vegetation shift primarily on increased atmospheric carbon dioxide levels, not climatic change.

The scientists measured the ratios of carbon-13 to carbon-12 and of oxygen-18 to oxygen-16 in carbonates from alluvial fan deposits in the Chihuahuan Desert. They found that the carbon isotope ratios in the geologic record changed, revealing a shift from grass-dominated to shrub-dominated vegetation some 7000 to 9000 years ago. They cited studies indicating that trees and shrubs have a competitive advantage when carbon dioxide levels rise significantly.

They also observed that the oxygen isotope ratios were relatively constant. "Oxygen isotope ratios depend on temperature and moisture," Cole says. "Because these ratios remained fairly constant in that period, we concluded that atmospheric carbon dioxide change, rather than climate change, was the dominant cause of the vegetation shifts."

The research results suggest that stable isotope ratios in well-preserved unaltered alluvial-fan soils could be useful indicators of global carbon-dioxide change. Thus, isotope ratios in the geologic record could fill gaps in knowledge about recent and ancient levels of atmospheric carbon dioxide and their relationship to vegetation and climate. Such information could be used to improve the ability of global climatic circulation models to predict future climate accurately. **ornl**

The photograph (above) and satellite image (below) show alluvial fan deposits in the Organ Mountains in New Mexico. The view in the photo is looking roughly to the west. In the geologic record in these deposits, an ORNL geochemist found stable isotopic evidence for a vegetation shift 7000 to 9000 years ago that resulted principally from an increase in atmospheric carbon dioxide.


ENDANGERED
EARTH
GLOBAL WARMING TREATIES
SOIL EROSION

Managing Global Change Information

By Frederick W. Stoss

Which human activities add to atmospheric concentrations of carbon dioxide (CO_2), the greenhouse gas that may promote warming of the earth's climate? ■ How would CO_2 emission restrictions change the use of fossil fuels? ■ How would increases in atmospheric CO_2 likely affect climate? ■ Can we see any evidence that the world is getting warmer? ■ What coastal-zone areas are more sensitive to potential sea-level rise from an accelerated melting of glaciers? ■ What is El Niño and how does it affect the earth's climate?

Fred Stoss studies a poster showing the endangered earth. The dark areas on the land represent forest and vegetation, and the light areas represent desert.

ORNL has more recently emerged as one of the preeminent environmental research centers in the world.

These are among the thousands of questions to which ORNL data analysts respond every year. Recently, the topic of global environmental change, including climate change, has grown in importance. At ORNL we have improved our understanding of the science underlying this major environmental issue. At the same time the Laboratory is playing a pivotal role in directing the data and information management activities for what some researchers consider the most information-intensive science project ever undertaken.

Long one of the world's leading energy R&D facilities, ORNL has more recently emerged as one of the preeminent environmental research centers in the world. Within ORNL's Environmental Sciences Division, the Environmental Information Analysis Program was established to serve as a focal point for the assimilation of data related to global environmental change. The three major components of the program are the Atmospheric Radiation Measurement Archive, the National Aeronautics and Space Administration's (NASA's) Earth Observing System Data and Information System Distributed Active Archive Center, and the Carbon Dioxide Information Analysis Center (CDIAC). The World Data Center–A for Atmospheric Trace Gases is located in CDIAC.

The earth's climate is determined by the amount of solar radiation absorbed by its surface and the amount of infrared radiation (heat) reflected back into space. The balance of the earth's heat depends on the input energy deposited by the sun and atmospheric abundances of radiatively active trace gases (the greenhouse gases), clouds, and aerosols. Greenhouse gases, which result from both natural and man-made processes, include carbon dioxide, nitrous oxide, methane, chlorofluorocarbons, halogenated compounds, and water vapor. Heat from the earth and its atmosphere that ordinarily radiates into outer space is instead absorbed by the greenhouse gases. This process boosts the heat energy in the lower atmosphere and on the earth's surface. As a result, the temperature of the lower atmosphere and the earth's surface increases, causing the planet to be warmer than usual.

Scientific success in understanding global environmental change depends on integration and management of numerous data sources, extensive data holdings, and a number of data products. Achieving true success in this endeavor requires an information system that stimulates and enables cooperation among many researchers, empowering them to contribute to the overall effort. The U.S. Global Change Data and Information System (GCDIS) provides for the management of data, the sharing and harvesting of information, the dissemination of ideas, and the establishment of a widespread community of collaborators. Both the Department of Energy (DOE) and ORNL participate in the GCDIS.

DOE Global Change Research Program

The issue of global change is international in scope. In 1988, the World Meteorological Organization and the United Nations Environment Programme established the Intergovernmental Panel on Climate Change to develop a scientific response strategy to investigate global climate change. The Office of Science and Technology Policy's Committee on Environment and Natural Resources oversees the U.S. multidisciplinary research effort. This committee developed the U.S. Global Change Research Program (GCRP) to provide a better understanding of the integrated earth system. This national program examines the possible implications of global change from scientific and social perspectives.

Under this program, DOE's GCRP aims to

- predict future atmospheric concentrations of carbon dioxide and other greenhouse gases;
- predict the rate and extent of potential global change resulting from an enhanced greenhouse effect;

- understand the direct impacts of greenhouse gas emissions on animal and plant life and the consequences of global change on ecosystems;

- develop the tools to assess the impacts of global change on production, delivery, and use of energy; and

- develop and assess technologies and practices to offset or limit the extent of adverse climate changes and increase understanding about differences in lifestyles resulting from the environmental, social, and economic consequences of global change.

An information program in the DOE GCRP serves as a scientific interface through which technical information can be obtained, evaluated, quality-assured, and distributed. Such attention to these data and information requirements fosters a greater exchange of information across disciplines and reduces the uncertainties with which decisions are made.

Information programs established at ORNL help DOE meet those objectives. As data are acquired or data products generated, they are made available to the research community, policymakers, educators, and the general interested public. Most data represent a significant investment of public support for research, and holding these data is a public trust.

Data Archives

The Earth Observing System Data and Information System is NASA's portion of the U.S. Global Change Data and Information System. This system manages data resulting from NASA's earth science research satellites and field measurement programs and other data essential for the interpretation of these measurements. Accordingly, Distributed Active Archive Centers (DAAC) are located at U.S. institutions to ensure that data will be available indefinitely in an easily usable form. These centers serve as the primary user interface to NASA's global change database.

ORNL was designated in 1993 as NASA's archive center for biogeochemical dynamics. This center gathers, performs quality-assurance checks on, documents, archives, and distributes data and data products in support of NASA's field projects and other global change research and policy-making efforts. Biogeochemical research, as it relates to ecological modeling and global change, has been a long and fruitful pursuit of staff at ORNL. The establishment of the DAAC at ORNL enhances the abilities of researchers at ORNL and other research centers worldwide to study further the dynamics of critical biogeochemical cycles in support of the U.S. GCRP.

Atmospheric Radiation Measurements

DOE designated the Laboratory as the archive for data generated by the Atmospheric Radiation Measurement (ARM) Program. A major goal of DOE is to improve predictive climate models for the earth and use these improved computer models to generate more nearly accurate predictions of the climate's response to increasing concentrations of greenhouse gases. Thus, the primary objective of this program is to improve the treatment of radiation and clouds in models used to predict climate changes, particularly general circulation models.

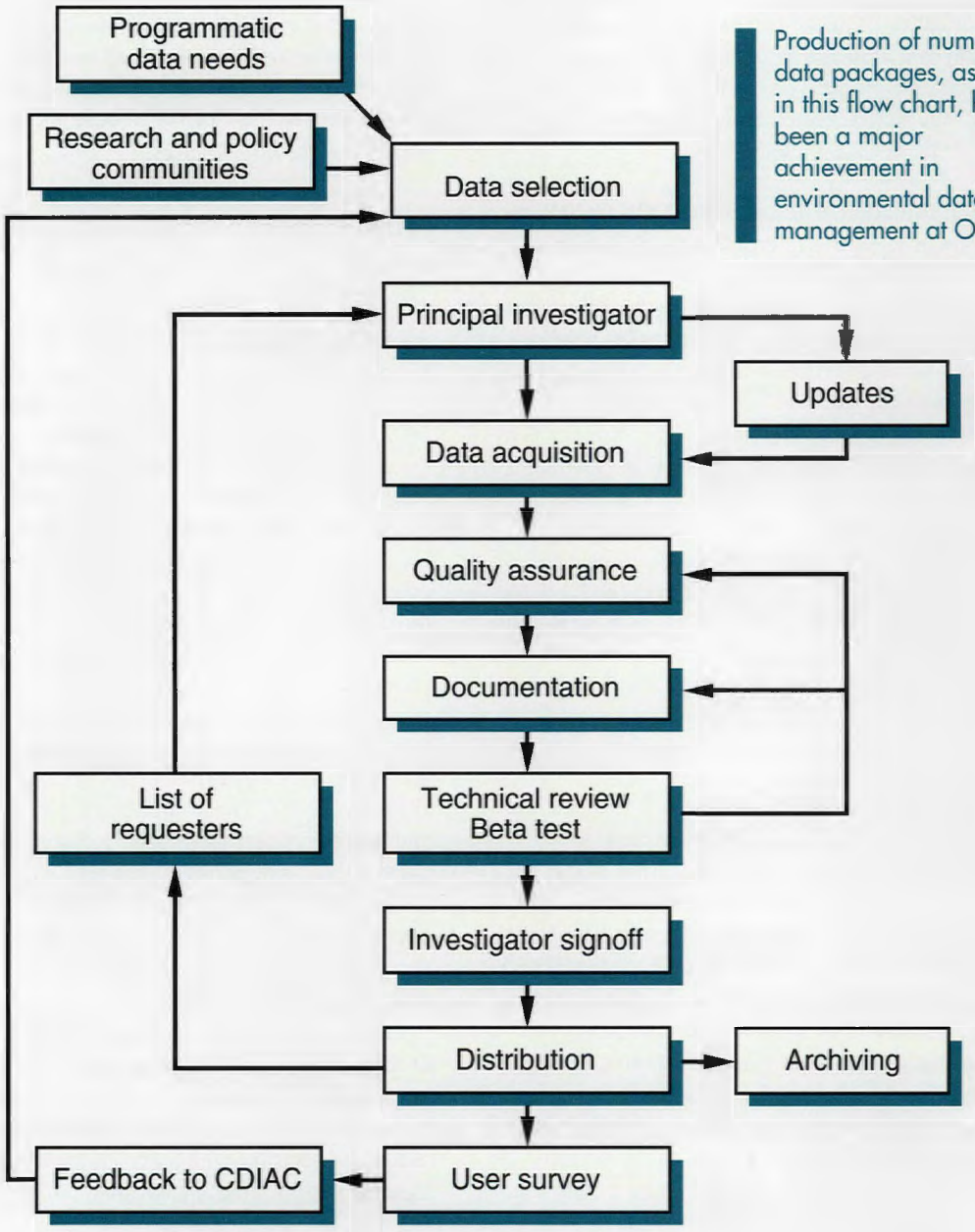
Achieving this goal entails measuring radiative fluxes, temperature, atmospheric composition, and wind velocity at five highly instrumented sites worldwide. These sites constitute the Cloud and Radiation Testbed (CART). Each site covers a geographic extent of 200 km on a side—about the current size of a grid cell in a general circulation model. It is estimated that each site will produce as many as 3 gigabytes of observation data per day.

Each site has a variety of instruments capable of measuring the radiative spectrum from near infrared through microwave frequencies. Such instruments vary in their tasks from scanning the radiative spectrum with a very narrow window to measuring total irradiance (direct and diffuse).

The center has initiated the delivery of its numeric data in other electronic formats including compact disc and on the Internet.

Each site also has an extensive capability of characterizing the physical dynamic structure of the atmosphere column directly above. These capabilities range from simple meteorological measurements, such as surface temperature, relative humidity, and wind speed, to more complex vertical and horizontal wind profiles and vertical profiles of the amount and species of water in the column over each site. Finally, image data on clouds will be provided by CART instruments on the earth's surface and instruments aboard observational satellites orbiting the earth.

The computing facility at each site gathers data from CART instruments. The data are transferred



Production of numeric data packages, as shown in this flow chart, has been a major achievement in environmental data management at ORNL.

Since 1985, the center's staff have responded to more than 60,000 requests for information.

CDIAC's principal information products are its fully documented numeric packages on which quality-assurance checks have been performed. Ready access to landmark (benchmark) data sets provides researchers, policymakers, and educators with information to increase the certainties (or decrease the uncertainties) with which environmental decisions are proposed. *Photograph by Tom Cerniglio and Curtis Boles.*

to the ARM Archive at ORNL. The ARM Archive provides the scientific community with the data taken from the sites, data developed from the merger of site data with information describing the quality-assurance checks, and contextual information. The ARM Archive can be accessed in a number of ways, and the data can be provided to users through a number of physical and electronic media.

CO_2 Information Analysis Center

When the Carbon Dioxide Information Center (CDIC) began in 1982 (the name was changed in 1986 to the Carbon Dioxide Information Analysis Center), greenhouse warming was a topic still primarily in the research arena and the center's role was, for the most part, one of distributing data *from* researchers *to* researchers. By the 1990s, however, when greenhouse warming was the subject of front-page newspaper articles, newsmagazine cover stories, congressional attention, and international conferences, CDIC's role—and its user community—had broadened considerably. The center has been fielding information requests from congressional staffers drafting or evaluating legislation; public-school students working on science fair projects; science reporters compiling data for stories; and researchers working in the applied, life, physical, political, and social sciences.

The center was established by DOE to support its carbon dioxide research program. Initially, CDIAC's mission was to identify, collect, quality-assure, document, and distribute information on the biogeochemistry of carbon dioxide and the effects of carbon dioxide on the earth's climate. As this research area matured, so did the center's scope. It now includes related global-change topics (e.g., other greenhouse gases and the effects of climate change on the environment).

The center's scope... now includes... global-change topics.

The primary focus of CDIAC is the production and distribution of numeric data packages and computer model packages. The center has produced more than 50 numeric packages, which have had quality-assurance checks and are documented databases on various global-change topics. These packages cover a wide variety of data, including long-term temperature and precipitation trends, changes in atmospheric and oceanic concentrations of carbon dioxide and other greenhouse gases, distribution of ecosystem

complexes, intensity and frequency of occurrence of storms, vulnerability of coastal regions to rising sea level, and effects of elevated carbon dioxide levels on plant growth. The center makes its data available in a variety of formats including hard copy and diskette. More recently, the center has initiated the delivery of its numeric data in other electronic formats including compact disc and on the Internet.

In 1993, CDIAC received an Exceptional Public Service Award from DOE.

In addition to producing and distributing data packages, CDIAC performs a number of other important information functions. For example, its newsletter *CDIAC Communications* is distributed to more than 10,000 subscribers in approximately 150 countries. The center publishes *Trends '93: A Compendium of Data on Global Change*, a *Catalog of Data Bases and Reports*, a *Catalog of Numeric Data Packages and Computer Model Packages*, *Glossary: Global Change Acronyms & Abbreviations, Carbon Dioxide and Climate*, and the *DOE Research Summary* (a four-page newsletter, each issue highlighting a specific DOE-sponsored research project). The center also produces *ARM Outreach*, a newsletter for DOE's Atmospheric Radiation Measurement Program.

Since 1985, the center's staff has responded to more than 60,000 requests for information and has distributed more than 100,000 technical reports and other information products. Staff is available to discuss both general and technical aspects of issues related to the carbon cycle; carbon dioxide, methane, and other trace gas emissions; and other climate change topics, including data and information management issues. CDIAC responds to requests from telephone calls, letters, and facsimile messages. However, in this new era of electronic communications, the center receives queries from a variety of electronic networks, including the Internet.

World Data Center at the Laboratory

CDIAC operates World Data Center–A for Atmospheric Trace Gases. The World Data Centers were established by the International Council of Scientific Unions in 1956. The U.S. National Academy of Sciences oversees World Data Center-A, which includes 12 data centers throughout the United States. As a World Data Center, CDIAC's ability to obtain and disseminate information is enhanced. The center shares responsibility with ORNL's Central Research Library for operating a regional information center established by the International Geosphere-Biosphere Program. This program, which has 50 information centers in 37 countries, expands the information services for the international global change community.

In 1993, CDIAC received an Exceptional Public Service Award from DOE during the center's annual program review, which recognized the center's significant achievements in support of DOE. The award citation, signed by Energy Secretary Hazel R. O'Leary, reads: "For exceptional service to the global change research community worldwide, creative innovations in the field of numerical data and information exchange, development of a model data center, achievement of international acclaim and recognition in the area of atmospheric trace gases, and significant contribution to the success of the Department of Energy's Global Change Research Program."

CDIAC was again given a high honor at its 1995 annual program review, when its DOE program manager, Bobbi Parra, presented each member of the CDIAC staff a Certificate of Achievement for "outstanding contributions in the collection, analysis, coordination, and dissemination of global change information, and specifically for the efforts being made in the electronic exchange of information." Certificates were signed by Martha A. Krebbs, director of DOE's Office of Energy Research.

To maintain its proactive position in global change information management activities, ORNL strives to keep informed about current research policy and information developments and needs at the international, national, and local levels. In addition to the exchange of data among researchers, ORNL has taken an active role in the networking of information among government agencies, industries, businesses, special libraries and information/data centers, academic institutions, nongovernmental organizations, and

special and public interest groups. Maintaining close professional contacts with individuals and organizations, CDIAC's networking capabilities include the dissemination of research results, policy initiatives, and education developments; objective technical interpretations and discussions of the technical aspects and information management related to carbon dioxide and climate change; referrals to other individuals or organizations; and access to resources relevant to individuals' information needs.

ORNL's networking capabilities have been further enhanced by active participation in the programs and organizational administration of professional societies, associations, and interagency and intergovernmental panels and working groups. Through these networking activities, ORNL can monitor the information needs of the broad global-change community and develop specific information products and services to help meet those needs. ornl

ORNL Offers Information on CO_2 *Just for You*

Want to find out more about global warming, its potential effects, and the role that future emissions of carbon dioxide might play? The information can be easily obtained, thanks to a highly accessible staff at ORNL that serves DOE's Global Change Research Program. Just ask your questions by calling, faxing, or sending postal or electronic mail messages.

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Global Change Data and Research

CDIAC has recently assisted the U. S. Global Change Data and Information System by constructing the GCDIS Home Page for the World Wide Web. The address for this comprehensive compilation of global change resources is http://www.gcdis.usgcrp.gov. The address for DOE's Global Change Research Program home page is http://www.er.doe.gov/production/oher/GC/ESD_gc.html.

BIOGRAPHICAL Sketch

FRED STOSS is employed by the University of Tennessee's Energy, Environment, and Resources Center. He has served as coordinator of outreach for ORNL's Carbon Dioxide Information Analysis Center (CDIAC). He holds an M.S. degree in zoology from State University of New York at Brockport and a master of library science degree from the School of Information Studies at Syracuse University. He is a member of the editorial boards of *The Electronic Green Journal* and of *Environmental Abstracts*. He currently serves as editor of *ES&H News* (Society for Technical Communication, Environmental, Safety, and Health Communicators Professional Interest Committee) and as chair of the American Library Association's Task Force on the Environment. Since 1991 he has represented CDIAC on the Library Information Subgroup of the U.S. Global Change Data Management Group.

Julia Kelley (left), Melissa Voss, and Marilyn Brown examine the latest issue of the *CADDET Newsletter*, which covers the work of the Center for the Analysis and Dissemination of Demonstrated Energy Technologies.

Promoting International Deployment of Greenhouse Gas Technologies

By Marilyn A. Brown, Julia S. Kelley, and Melissa K. Voss

Increasing emissions of greenhouse gases from human activities are predicted to lead to significant global warming and possibly undesirable environmental effects by the middle of the next century. These gases trap solar energy that is reradiated from the earth's surface, raising its temperature. The gases—carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons (CFCs)—are emitted as the result of a wide range of anthropogenic activities, including the production and conversion of energy from fossil fuels, the operation of air conditioning and refrigeration equipment, coal mining,

ORNL is responsible for managing and supporting the U.S. involvement in many of these implementing agreements.

domestic sewage treatment, and the manufacture of cement and nylon. To slow global warming, technologies are being developed, promoted, and deployed to reduce these emissions.

To make a practical response to global environmental issues such as greenhouse gas emissions, it is recognized that international collaboration is needed. Because of the accelerating pace of technology innovation and the increasingly interconnected world economy, national efforts to adapt to global environmental challenges are no longer sufficient. Through international collaboration, scarce resources can be shared and technological solutions can be adapted and replicated.

Several international cooperative agreements are now in place to accelerate worldwide deployment of technologies that mitigate greenhouse gas emissions, and ORNL staff perform work in support of these agreements. Because energy efficiency and renewable energy technologies have vast potential for reducing greenhouse gas emissions, much of the support for these international activities comes from DOE's Office of Energy Efficiency and Renewable Energy, which funds the ORNL work. In supporting these activities, DOE recognizes the importance of developing foreign as well as domestic markets for new and improved high-efficiency and renewable energy technologies produced in the United States. Widespread deployment of these technologies should reduce energy costs to consumers, improve the nation's standard of living, increase energy security, and enhance environmental quality.

Because of its exploding population, increasing buying power, and growing energy consumption, the developing world is a key market for energy-efficiency and renewable energy technologies. The two main forces driving energy demand in developing countries have been population growth and economic development. The growth in energy use has for some time been fastest in developing countries. In the past decade, for instance, the demand for energy in the developing world has grown by 49%, compared with a 14% increase in the developed world. At these rates of growth, the World Energy Council Commission estimated in 1993 that, by 2010, developing countries will account for the major part of the world's greenhouse gas emissions from burning fuels.

To date, 150 countries have signed the United Nations Framework Convention on Climate Change, which commits them to work toward controlling and reducing greenhouse gas emissions. Thus, there is a sizeable commitment around the world to implementing greenhouse gas mitigation technologies. The International Energy Agency (IEA) has established a number of information centers that assist the efforts of these countries. ORNL's role in supporting one of these centers—the Greenhouse Gas Technology Information Exchange (GREENTIE)—is the primary focus of this article, although ORNL's involvement with two other IEA activities is also highlighted.

The IEA was created in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD). 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" that provide the legal mechanisms and management structure for collaboration.

Currently, 42 implementing agreements are in effect, covering the following topics:

- Energy technology information centers (7 agreements)
- Fossil fuel technologies (7 agreements)
- Renewable energy technologies (20 agreements)
- Nuclear fusion technologies (8 agreements).

ORNL is responsible for managing and supporting the U.S. involvement in many of these implementing agreements. In addition to collaborating with GREENTIE, ORNL is involved with the following other IEA implementing agreements, either as executive committee members, national team leaders, or operating agents: the Center for the Analysis and

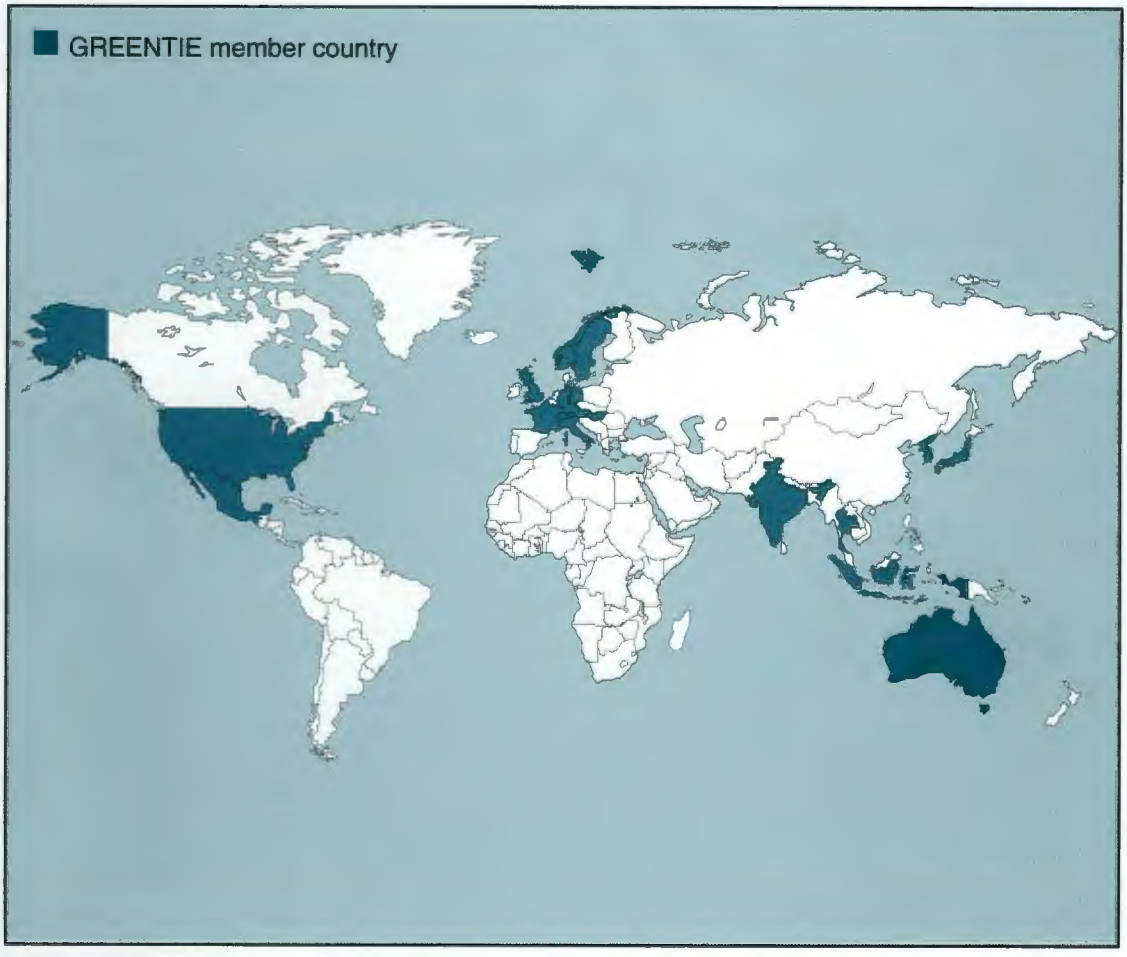
Dissemination of Demonstrated Energy Technologies, Heat Pump Program, Buildings and Community Systems, Alternative Motor Fuels, and Fusion Energy Stellerator Concept.

GREENTIE

GREENTIE was formed under the auspices of IEA in October 1993. DOE became an official member of GREENTIE in 1994, at which point ORNL was asked to help DOE carry out the GREENTIE mission. 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 decisionmakers and users. By helping to inform decisionmakers worldwide about available greenhouse gas technologies, GREENTIE will contribute to increased exports and unit sales of energy-efficient and renewable energy products and will help reduce the adverse impacts of fossil-fuel consumption on the global environment.

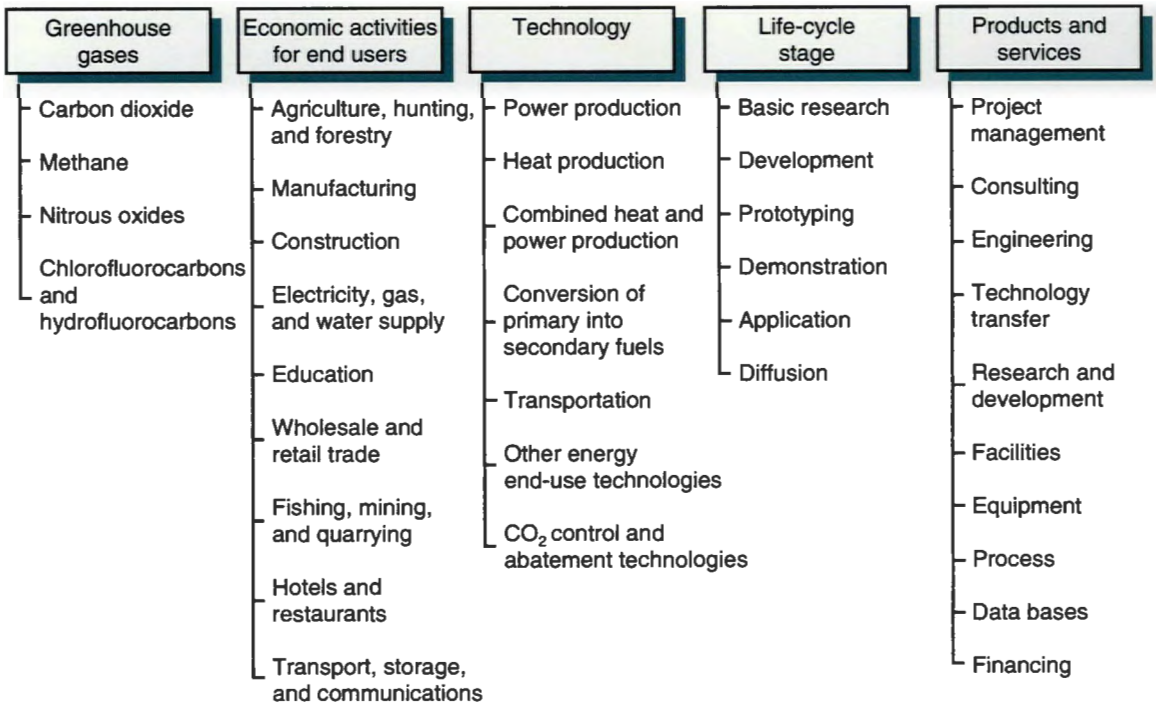
Greenhouse gas technologies include a wide array of options for reducing emissions of greenhouse gases. Two energy-efficiency approaches are being taken to abate the large

GREENTIE's primary product will be a directory of information about suppliers.



These shaded countries currently participate in GREENTIE.

The capabilities of organizations listed in the IEA GREENTIE directory are categorized.



GREENTIE also deals with techniques for separating, recovering, and disposing of carbon dioxide.

emissions of carbon dioxide from combustion of fossil fuels. First, advanced technologies are being developed to improve the efficiency with which stored energy is converted to useful energy. For example, pressurized fluidized-bed combustion is gaining favor as an energy source because it extracts more heat from burning coal than do other coal-combustion methods for generating electricity. As a result of its high thermal efficiency, pressurized fluidized-bed combustion emits less carbon dioxide per unit of energy produced than do other types of coal power plants. Other examples include gas turbine technologies and fuel cells.

Second, to further reduce carbon dioxide emissions from fossil-fuel combustion, technologies are being developed to improve the efficiency with which energy is consumed in various applications. Examples of these end-use efficiency improvements include compact fluorescent lighting, adjustable-speed electric motors and drives, pulse combustion boilers, and compressed natural gas vehicles.

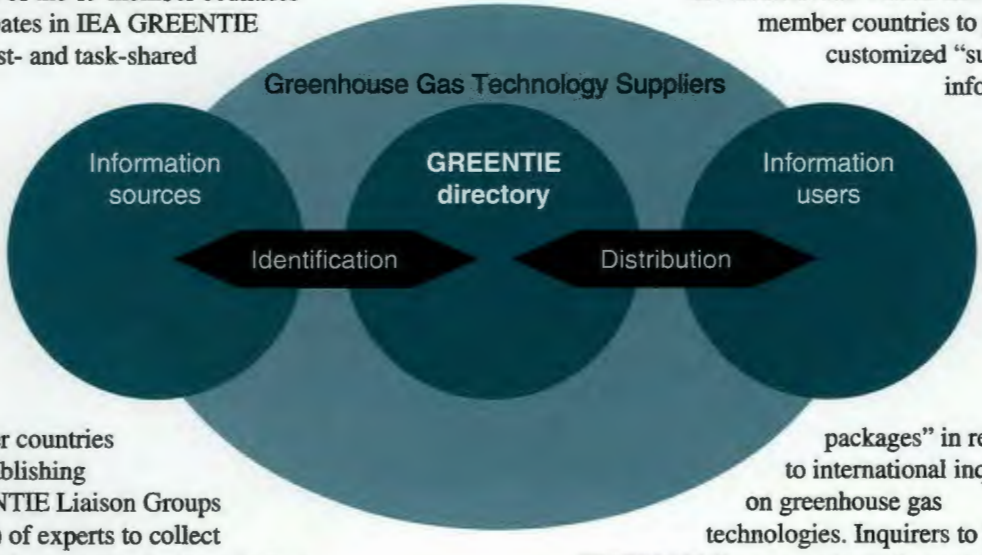
In contrast to fossil energy sources, renewable energy forms such as solar, wind, hydro, tidal, and wave energy, and the sustainable use of biomass are either carbon-free or carbon-neutral. Thus, renewable energy technologies are a major thrust of the GREENTIE program. GREENTIE also deals with techniques for separating, recovering, and disposing of carbon dioxide once it has been produced.

Technologies for reducing methane emissions are similarly diverse, reflecting the wide range of anthropogenic sources of emissions: natural gas systems, coal mining, waste disposal, wastewater

treatment, and domesticated livestock. Examples of methane-reducing technologies include detection of leaks of methane from and repair of natural gas pipelines, improved oil and natural gas compressor operations, and installation of landfill gas recovery systems.

This new implementing agreement was created in response to IEA member nations' concerns about the global rise in temperature caused by manmade changes in the composition of the atmosphere and to their questions about appropriate remedial action. Currently, 19 member countries participate in this IEA implementing agreement: 13 are members of IEA/OECD and the remaining nations are developing countries. By extending membership to non-IEA countries, GREENTIE is acknowledging the fact that the developing world must be part of any internationally effective program to abate greenhouse gas emissions. The GREENTIE Center in the Netherlands acts as a focal point for information and technology sharing among these 19 countries.

Each of the 19 member countries participates in IEA GREENTIE on a cost- and task-shared basis.



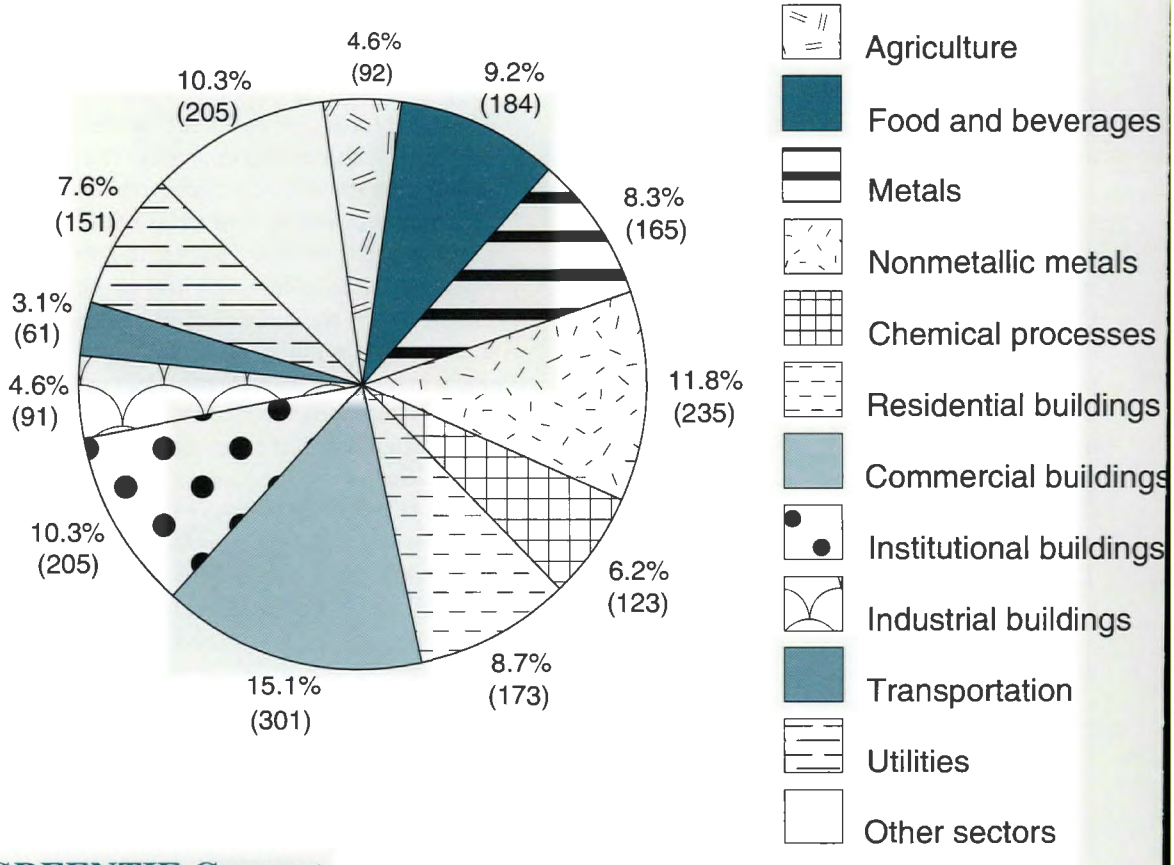
Under the GREENTIE concept, people needing information on suppliers of greenhouse gas technologies are connected to the information sources.

Member countries are establishing GREENTIE Liaison Groups (GLGs) of experts to collect information on organizations in their countries that wish to promote their organizational capabilities free of charge internationally. Each GLG also promotes GREENTIE within its country and provides assistance to users. The U.S. GREENTIE Liaison Group was established by DOE in 1995, with assistance from ORNL.

GREENTIE's primary product is 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 completed the first edition of a directory of this supplier information and made the directory available to all member countries. The directory, which is on the Internet, categorizes the capabilities of suppliers in terms of the greenhouse gases that their products and technologies help to mitigate; the economic activities of the users of their products and technologies; and the types of greenhouse gas mitigation technologies, products, and services they offer. During 1995, ORNL was charged with the task of contributing directory information on 2500 organizations located in the United States.

The GREENTIE directory facilitates the international exchange of information on greenhouse gas technology options. It also enables the GREENTIE Center and member countries to prepare customized "supplier information packages" in response to international inquiries on greenhouse gas technologies. Inquirers to the GREENTIE Center receive information about technology options and companies located in the United States and other member countries that can meet their specific needs. This information forges links between motivated potential buyers and prospective member country suppliers.

CADDET's 1658 demonstration projects are broken down by end-use sector.



GREENTIE Concept

The GREENTIE Center coordinates its activities with other IEA implementing agreements and publishes a free newsletter called GREENTIMES. It also promotes GREENTIE worldwide by collaborating with other international energy or environmental organizations and by participating in international conferences and meetings.

Included in the outlook for future GREENTIE products are (1) country-specific analyses of technology options prepared by member countries and (2) an electronic communications capability. It is anticipated that, by 1996, an Internet-based system will connect GREENTIE to existing on-line information sources such as DOE's Energy Efficiency and Renewable Energy Network. GREENTIE will then be able to offer a "smart window" to a wealth of information available globally. Potential users will be able to search the GREENTIE directory themselves, compare technologies, and contact suppliers.

Ultimately, the combination of a directory of information on suppliers, customized supplier information packages, country-specific technology analyses, and liaison group activities will expedite the worldwide dissemination of information on cost-effective technologies for reducing greenhouse gas emissions. ornl

CADDET: Promoting Energy Technologies

Many energy-efficient and renewable energy technologies have been documented in demonstration projects to be technically feasible and economically attractive. Examples include various heat recovery systems, high-efficiency motors and drives, geothermal heat pumps, and thermal storage systems. Widespread adoption of these technologies often is delayed because data about their successful performance do not reach potential users. Information about a range of these technologies is available from the international Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET).

CADDET was formed by the IEA in 1988 to collect and disseminate information on demonstration projects that have produced data on the successful economic and technical performance of energy-efficient end-use technologies. The center recognizes that tangible evidence of technical and economic acceptability produced by demonstration projects can effectively accelerate the replication of successful technologies. The ultimate goal of U.S. 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 1993, CADDET was expanded into two branches—CADDET Energy Efficiency and CADDET Renewable Energy. In the United States, involvement with the CADDET Energy Efficiency Annex is coordinated by ORNL for DOE. DOE's National Renewable Energy Laboratory in Golden, Colorado, provides technical support for U.S. involvement in the CADDET Renewable Energy Annex.

Currently, 15 member countries participate in this IEA agreement on a cost- and task-shared basis. The CADDET Energy Efficiency Operating Agent in the Netherlands and the CADDET Renewables Operating Agent in England act as focal points for communications. Member countries have established "national teams" of experts to search for demonstrations of new energy-saving technologies that are suitable for replication in other parts of the world. The teams also assist with the distribution of CADDET information on demonstrated energy technologies to appropriate audiences. The U.S. National Team, led by ORNL, is made up of approximately 75 representatives from technical, professional, and trade organizations; private industry; utilities; and local, state, and federal agencies.

At the heart of the CADDET operation is a computerized register of information on more than 1600 energy technology demonstration projects. Each member country is responsible for preparing the register's database 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.* Each brochure describes the technology being demonstrated, the setting, the cost of the project, the energy saved, and other findings concerning the operation of the technology. Each brochure also lists names of individuals who can be contacted for further information.

The most in-depth of the CADDET products are the analysis reports. These reports use experts from CADDET member countries to compare the technical and economic performance of a particular type of technology across a range of demonstrations. Fourteen analysis reports have been produced to date.

Finally, CADDET also produces quarterly newsletters, which are currently distributed to more than 10,000 subscribers worldwide. Each issue focuses on a specific technical topic and features international articles, news items, abstracts of recent publications, and meeting notices.

CADDET's mission has expanded beyond identifying and analyzing information about demonstrations of new energy-saving technologies. To disseminate more effectively the information it collects, CADDET has increased its use of marketing techniques to target audiences that would benefit most from the information. Also, it evaluates and documents the performance of the program. Each national team performs marketing and evaluation projects, such as subscriber surveys, exhibits at trade shows, and targeted mailings.

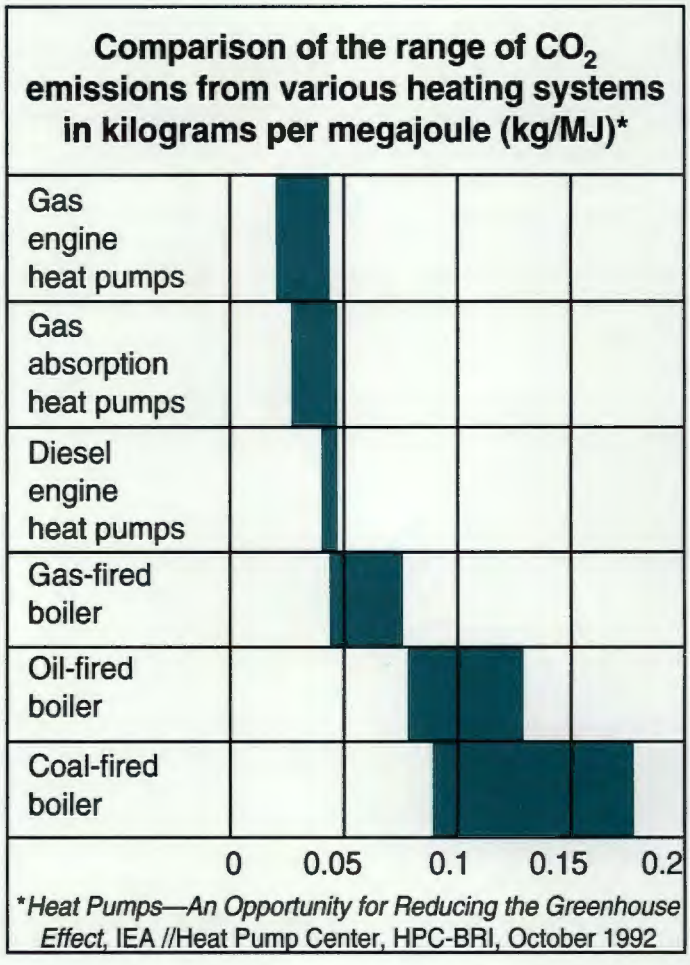
In addition, the United States has led the way in promoting CADDET via the Internet by making all U.S. *Register* entries available on the World Wide Web. During its first 9 months on the Web, the *Register* was accessed more than 1500 times. As a result of this success, CADDET information on the Internet will likely be expanded to include the entire *Register* database and the full text of selected technical brochures. The address of the U.S. CADDET Register on the Internet is: http://www.ornl.gov/CADDET/caddet_db.html.

An International Program on Heat Pump Technologies

Electric heat pumps are used to heat and cool buildings. Through improvements of the efficiency of this end-use technology, less fossil fuel will be burned, resulting in lower emissions of carbon dioxide. New heat pumps must also be designed to use refrigerants that do not contain chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs), which are also greenhouse gases. Hence, the goal of an international heat pump program is the development and deployment of an energy-efficient, environmentally acceptable heat pump to reduce greenhouse gas emissions.

In addition to supporting GREENTIE and CADDET, DOE's Office of Energy Efficiency and Renewable Energy sponsors U.S. participation in the IEA Implementing Agreement for a program of research, development, demonstration, and promotion of heat pumping technologies. ORNL staff provide technical and administrative support to this IEA Heat Pump Program and chair the group of experts that compose the U.S. National Team. International collaboration and technology transfer are made possible by the volunteer efforts of each country's national team. The U.S. National Team has strong industry representation from organizations such as the Carrier Corporation, the Electric Power Research Institute, the Gas Research Institute, Inter-City Products, Lennox Industries, and the Trane Company.

Since 1978, the IEA Heat Pump Program has sponsored more than 20 "annexes," or collaborative projects, in which 16 countries have participated. The United States 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 predict the market penetration, potential energy savings, and potential emissions reductions of industrial heat pumps. Annex 18 has brought together international properties experts who are collaborating to



In this comparison of the range of carbon dioxide emissions from various heating systems (in kilograms per megajoule), coal-fired boilers are the largest emitters and diesel engine heat pumps are the smallest.

produce bulletins, a database of experimental work and literature, and research surveys to provide a reliable source of information on refrigerant properties.

Annex 16, the Heat Pump Center (HPC), provides a means of collecting, analyzing, and disseminating technical, market, regulatory, and environmental information concerning heat pumps. 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. Twenty-five countries recently submitted national position papers for an analysis report entitled "International Heat Pump Status and Policy Review." This report was prepared in close collaboration with the International Institute of Refrigeration and is the most comprehensive assessment of the global heat pump situation to date. Other recent multinational analyses 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 more than 800 readers in the United States and to more than 4000 readers worldwide. The March 1995 issue focused on replacements for CFCs and HCFCs, with two articles and the editorial written by U.S. authors. The articles were provided by the Air-Conditioning and Refrigeration Institute (ARI) and the Trane Company, and the editorial was submitted by the International Institute of Ammonia Refrigeration. Proceedings of two recent HPC co-sponsored 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."

Goals of this IEA program include dissemination and promotion of collaborative Heat Pump Program annex results to facilitate the rapid development and deployment of environmentally friendly heat pumps.

information

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Reference

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BIOGRAPHICAL Sketches

MARILYN A. BROWN is deputy director of ORNL's Energy Efficiency and Renewable Energy Program. She has a Ph.D. degree in geography from Ohio State University and a master's degree in resource planning from the University of Massachusetts. Before coming to ORNL in 1984, she was an associate professor at the University of Illinois. Her research at ORNL has examined issues surrounding the commercialization of new energy technologies and frameworks and methods to evaluate the impacts of federal and utility-operated conservation and renewable energy programs. She has served on many editorial boards and advisory panels and has authored more than 120 publications. She has received awards for her research from the Association of American Geographers, the Technology Transfer Society, and the Association for Women in Science.

JULIA S. KELLEY is a project manager in the Integrated Project Management Section of Information Management Services in Lockheed Martin Energy Systems. She received her master's degree in library and information science from the University of Kentucky in 1987. Following a position as a research librarian at the *Knoxville News-Sentinel*, she joined ORNL in 1991. She is a member of the Amercian Society for Information Science.

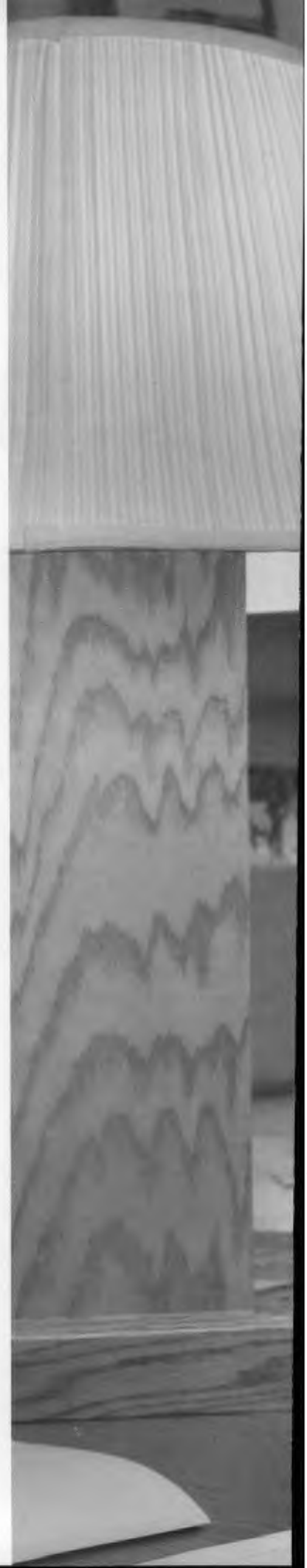
MELISSA K. VOSS is a marketing analyst in the Efficiency and Renewables Research Section of ORNL's Energy Division. Her work includes creating outreach materials that promote energy-efficient technologies at ORNL's Buildings Technology Center and implementing marketing strategies for three International Energy Agency programs. In 1993, she received a master of business administration degree in marketing from Western Illinois University and began working at ORNL. She is a member of the American Marketing Association.

Electric Utilities and Energy Efficiency

By Eric Hirst

When we think about our local electric utility (and most of us do that only rarely), we likely envision power plants, transmission lines, the meter on the side of our house, and, of course, our monthly electric bill. Mostly, we view utilities as providers of electric power. ■ However, more and more utilities now provide both electricity and related services to help customers reduce their electric bills. Such services also have a social benefit: because energy demand is controlled, emissions of carbon dioxide are reduced, slowing global warming. These services are provided by

Eric Hirst is a corporate fellow with ORNL.



demand-side management (DSM) programs. Using DSM, utilities can affect the amount and timing of customer electricity use. They can reduce the amount of electricity use by improving the technical and operational efficiency with which customers use electricity. The timing of electricity use can be influenced by direct-load control programs in which the utility controls equipment at the customer site and by electricity-pricing options that vary the price of electricity with time of use. ■ Research on utility DSM programs has been conducted in ORNL's Energy Division and supported by the Department of Energy and its predecessor agencies since 1970. Here I give examples of some technologies promoted by these programs, explain why utilities are running such programs, and mention other forces that affect electricity use.

DSM Examples

All public buildings, including all ORNL facilities, contain exit signs. These signs use electricity 24 hours a day, every day of the year. The typical exit sign has two 20-W incandescent bulbs. These bulbs last only 2000 hours, so they must be replaced four times a year. Compact fluorescent bulbs, however, last four times longer and use much less electricity. Light-emitting diodes need to be replaced only once every 5 years and consume only 2 W per exit sign (see figure on p. 55). Although each exit sign uses only a small amount of electricity, the total potential savings are large because about 40 million such signs exist in the United States.

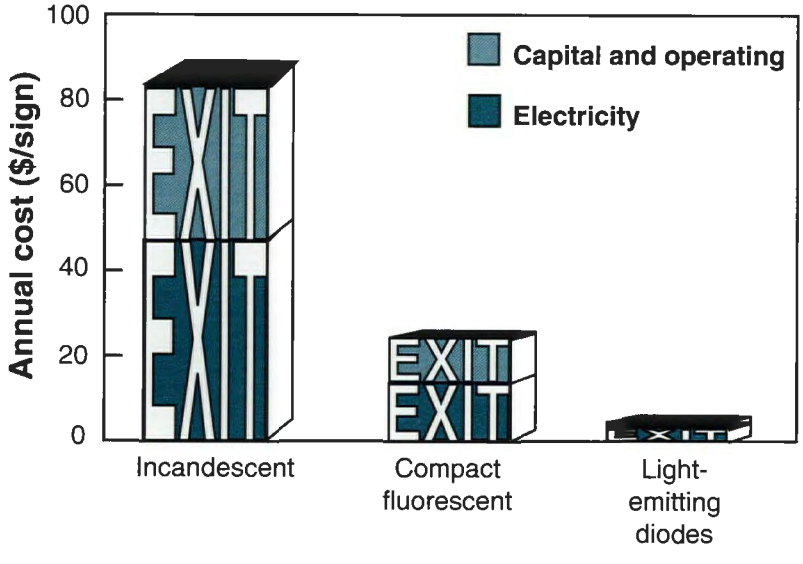
The exit sign represents only one small example of the many energy-efficiency opportunities surrounding us. We can improve the efficiency with which we use electricity for every major use, including heating, lighting, air conditioning, office equipment, motors, and industrial processes. These improvements involve the use of new, more efficient technologies as well as better operating practices. For example, improved operation of heating, ventilation, and air-conditioning systems in commercial buildings can often cut electric bills, with no capital investment, by 10 to 15%. Typical operational changes include cleaning air filters, lubricating dampers, and ensuring that controls work properly.

The cost to produce electricity varies enormously by season and hour of the day. Therefore, utilities are interested in reducing demands at critical times, when it is expensive to generate electricity. To encourage customers to cut demand or shift loads to other times of the day, utilities offer interruptible rates (lower rates in exchange for giving the utility the right to interrupt electrical service), time-of-use pricing, or direct-load control programs. The second figure on p. 55 shows the demand reductions that Florida Power and Light obtained from some of its largest commercial and industrial customers. These customers agreed to reduce demands during certain critical times in return for a lower electric bill.

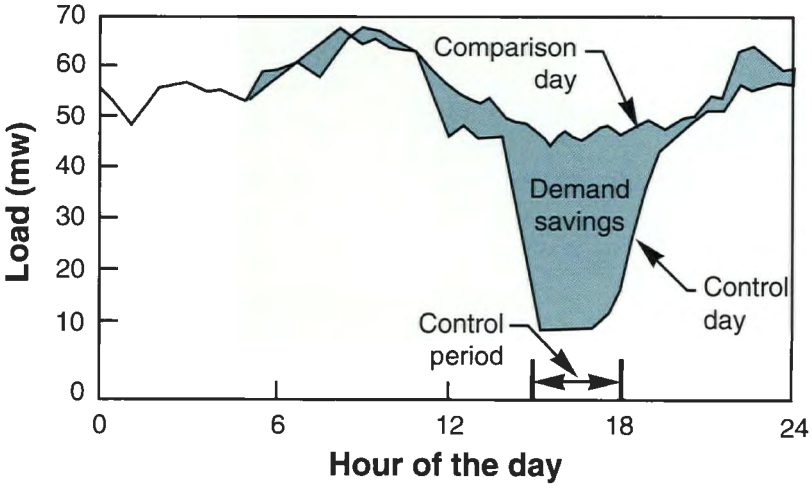
Types of DSM Programs

Utilities run different kinds of DSM programs. Early programs during the 1970s focused on providing general information, primarily through flyers, newspaper ads, and workshops. Then, around 1980, utilities began to offer site-specific information, in which a utility staffer inspects the customer's facility (home, office building, or factory) and offers specific suggestions along with estimates of installation costs and savings for each measure. Many utilities now help their customers pay for the extra cost of energy-efficiency measures through rebates or low-interest loans. In some cases, it is cheaper (for

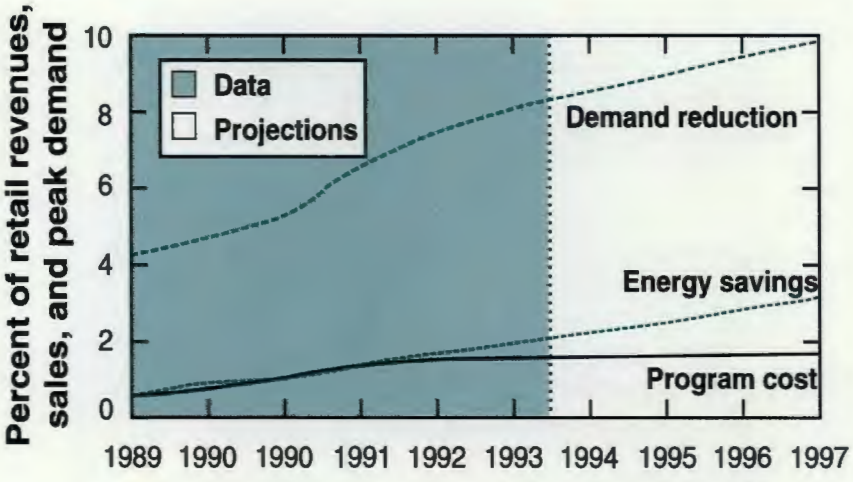
We can improve the efficiency with which we use electricity for every major use.



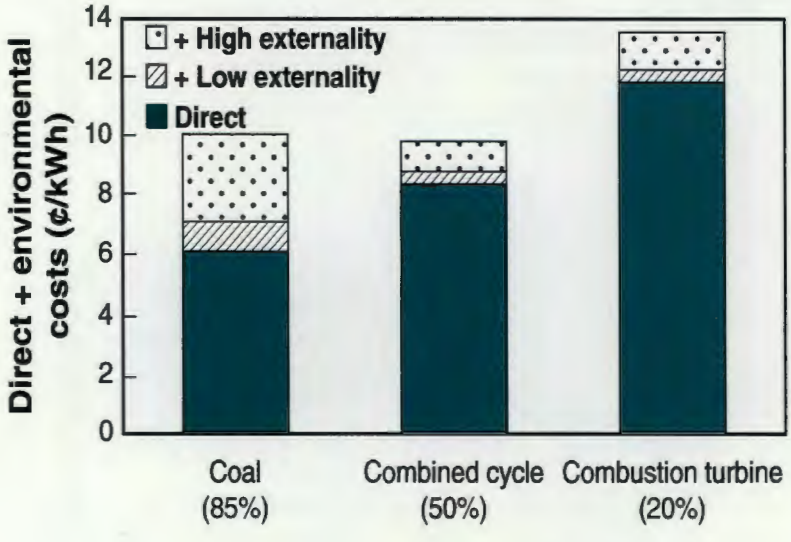
The annual cost of owning (capital and labor) and operating (electricity) different kinds of exit signs depends on whether they are illuminated by incandescent lights, compact fluorescent lights, or light-emitting diodes.



The 12 large commercial and industrial customers participating in Florida Power and Light's load-control program experienced a reduction in summer demand for electricity. At 3 p.m., for example, the demand for power was 36 megawatts lower than it was on comparison days when customers were not required to cut demand.



Costs and effects (energy and demand reductions) of electric-utility DSM programs from 1989 through 1993 and early-1994 projections to 1998.



The cost-effectiveness of DSM programs depends on the environmental costs of using a particular fuel for electricity production. The numbers in parentheses beneath each bar are the assumed capacity factors for each type of power plant.

low-cost measures, in particular) for the utility to install the measures during the energy audit, so these utilities run direct-installation programs. Because the structure of electricity prices (charges for energy and demand) affect customer usage, modifying these pricing schedules can be considered a form of DSM.

Finally, some utilities are now running so-called market-transformation programs. Rather than dealing one-on-one with individual customers, these utilities are moving "upstream" in an effort to influence the actions of contractors, builders, retailers, distributors, and even manufacturers. For example, instead of offering a $50 rebate to every customer who buys an efficient refrigerator, why not get the manufacturer to produce only more efficient units? That was the response of a group of about 25 utilities. In what is informally known as the Golden Carrot program (and officially known as the Super-Efficient Refrigerator Program), these utilities pooled about $30 million and ran a competition to select a manufacturer who could develop a refrigerator at least 30% more efficient than the 1993 federal standard. Whirlpool won the competition and its new, highly efficient refrigerators are now in stores in the service areas of the participating utilities.

Between 1989 and 1994, electric-utility expenditures on DSM programs more than tripled, the potential reduction in peak demand doubled, and the energy savings tripled. In 1994, U.S. electric utilities spent about 1.5% of their total revenues on DSM programs; in return, these programs cut annual sales by 1.9% and cut peak demands by 7.3%, reducing the need to construct power plants. Furthermore, the utility projections

as of early 1994 show continued growth in DSM spending and effects (see figure at top of p. 56). Recently, many utilities have reduced their planned DSM expenditures, and, to a lesser extent, their planned energy and demand reductions in response to growing competition in the electricity industry. These data and projections make two points. First, DSM is a nontrivial utility activity that is having a measurable effect on utility sales, demand, and revenues. Second, even though DSM effects are increasing, DSM alone will not meet the growing demand for electricity in the United States. The nation will continue to need new power plants, transmission lines, and distribution systems.

These national figures mask substantial regional variation in DSM activity. The majority of DSM utilities are in seven states—California, Florida, Massachusetts, North Carolina, New York, Washington, and Wisconsin. The leading utilities are concentrated along the east coast (especially the Northeast), west coast, and upper Midwest. In the Southeast, the Florida utilities, Duke Power (in North and South Carolina), and Georgia Power are among the leaders.

Why Utilities Run DSM Programs

At first glance, it seems ridiculous for a company to encourage its customers to use less of its product. Does General Motors urge us to carpool and keep our cars longer? Does Pizza Hut tell us to eat more vegetables and fruits and avoid fatty cheeses and meats?

Electric utilities are different in three ways. First, they are regulated monopolies. If you don't like Sony stereos, you can always buy from Zenith or Panasonic. But if you don't like your local utility, you have to move outside its service area to be able to buy electricity from another entity. Because of utilities' monopoly status, they are regulated by state agencies, the public utility commissions. Second, electricity is considered a necessity "clothed with the public interest." Third, the production and transmission of electricity cause serious environmental problems, including emissions of greenhouse gases.

Utility experience during the past several years shows that DSM programs provide resources that cost-effectively substitute for power plants. That is, direct-load-control programs and interruptible rates provide the same types of services that a combustion turbine does but at lower cost. Similarly, energy-efficiency programs are often low-cost alternatives to the construction and operation of baseload coal and nuclear plants.

The recognition that DSM is a "resource," analogous to power plants, led to a new way of planning for electric utilities, called integrated resource planning (IRP). IRP involves utility consideration of a broad array of ways to meet customer energy-service needs, rather than only building and operating power plants. Utilities now consider purchasing electricity from other utilities and from nonutility entities, repowering and extending the life of existing plants, DSM programs, transmission and distribution improvements, and pricing as alternative ways to meet the growing demand for energy services.

Utilities and their regulators recognize also the environmental benefits of DSM programs. Because these nonpolluting programs substitute for power plants, we can keep our homes and offices cool in the summer and warm in the winter with fewer air-pollution emissions. The bottom figure on pg. 56 shows the direct and environmental costs for three types of power plants: a baseload coal plant, an intermediate combined-cycle gas-fired plant, and a peaking simple-cycle combustion turbine. The bottom portion of each bar shows the direct economic cost of building and operating each plant. The upper two bars show the range of estimates of damages caused by the air pollution produced by these plants plus the damages associated with carbon dioxide emissions. (I show a range because there is considerable uncertainty about the costs to society of power-plant emissions.) DSM avoids these emissions. Therefore, it is more cost effective than would appear from consideration of the direct economic costs only.

In addition, utilities run DSM programs because they and their regulators recognize that

Energy-efficiency programs are often low-cost alternatives to the construction and operation of baseload coal and nuclear plants.

utilities can help overcome the market barriers that keep customers, in all sectors of the economy, from adopting what would otherwise be cost-effective energy-efficiency measures (see table below). For example, in tenant-occupied buildings, the occupants have no incentive to install efficiency measures because they don't own the building. The owner, on the other hand, has no incentive to install such measures because he doesn't pay the utility bills. Utilities can help cut the "transaction costs" associated with selecting and installing suitable measures. Utilities are well situated to assist here because of their long-standing relationships and monthly contacts with all customers. Utilities have substantial technical competence and are generally regarded as reliable sources of information. And utilities have intimate knowledge of electricity consumption patterns and trends and of the costs of providing electrical services.

Barriers to improving U.S. energy efficiency

Structural barriers—conditions beyond the control of the end user

- distortions in electricity pricing
- supply infrastructure limitations

Behavioral barriers—conditions that characterize end users

- efficiency attitudes and awareness
- perceived riskiness of efficiency measures
- obtaining and processing information
- limited access to capitol
- misplaced incentives
- inconvenience, loss of amenities

Other Forces That Affect Electricity Use

The U.S. electric sector now accounts for 36% of U.S. primary energy consumption. This share is increasing as our homes and economy become more electrified. Consider, for example, the proliferation of electricity-using office equipment that barely existed a decade ago, including personal computers, printers, modems, and fax machines.

A recent study for the Electric Power Research Institute examined the various forces likely to affect electricity use between 1990 and 2010. The primary factor that will increase electricity use is growth in population, households, businesses, and industry. In addition, changes in the structure of the economy (especially electrification of industry) will also increase electricity use. Offsetting some of this growth are normal market forces and government efficiency standards, as well as utility DSM. Government standards have had substantial effects already. The efficiency of new refrigerators in 1993 was almost triple the efficiency of new refrigerators sold in 1972. In addition, the fraction of new homes built in the Pacific Northwest that meets the region's Model Conservation Standards grew from about 5% in 1984 to more than 90% a decade later.

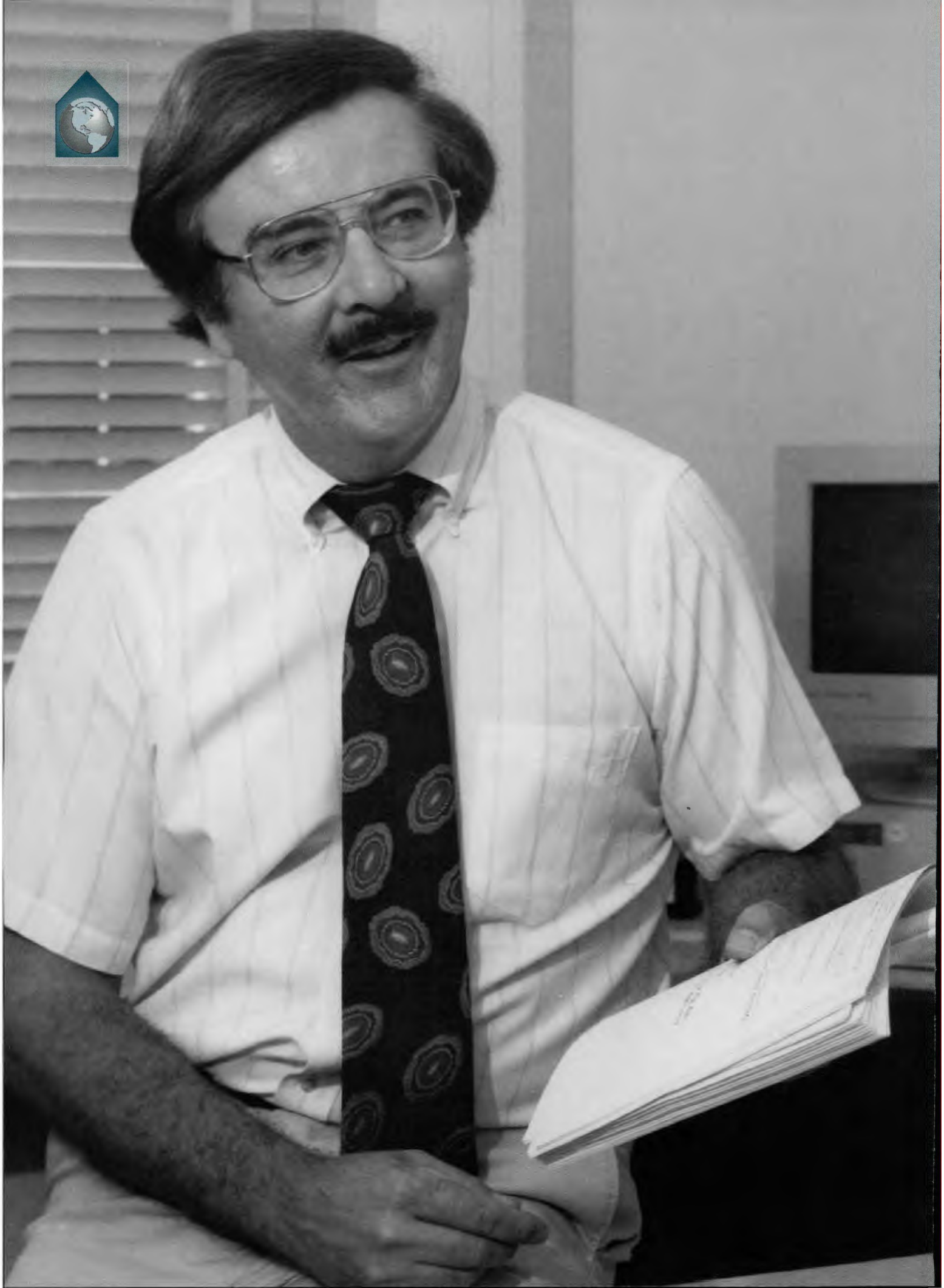
Outlook

What is the future for utility DSM programs? Positive factors include the development and commercialization of new technologies (including those developed at ORNL) that provide improved services at lower cost, utility experience in marketing such programs, and growing pressures to protect the environment and slow global warming by limiting emissions from fossil-fuel plants. Offsetting these positive factors are concerns that the actual performance of DSM measures is generally less than engineers predict and the effects of increasing competition in the electric industry. Increasing competition is driving down the cost of new supply options, which makes DSM less cost effective and exerts strong pressure to keep retail prices low.

I think that DSM's substantial benefits, both to individual consumers and to society as a whole, imply a bright future for energy efficiency. These programs provide capacity and energy resources that can defer construction of new power plants and transmission lines. They are cost effective, they improve environmental quality, and they provide better customer service. ornl

BIOGRAPHICAL Sketch

ERIC HIRST, a research engineer with ORNL since 1970, is a corporate fellow in ORNL's Energy Division. His research focuses on competition and restructuring in the electricity industry, resource planning for electric utilities, and demand-side management. Hirst spent a year (1992–93) with the Land and Water Fund of the Rockies, an environmental center in Colorado. He worked with the LAW Fund to encourage electric utilities to adopt integrated resource planning and demand-side management programs in the Rocky Mountain states. Previously, Hirst was on assignment with Puget Sound Power & Light, in Bellevue, Washington, in 1986–87, helping Puget staff prepare their initial resource plan. Hirst was also on assignment with the Minnesota Energy Agency in 1979. Earlier he spent 15 months as director of the Office of Transportation Research in the Federal Energy Administration. He holds a Ph.D. degree in mechanical engineering from Stanford University. Hirst is author of a book on energy efficiency in buildings. He is a member of the board of directors of the American Council for an Energy-Efficient Economy and of several editorial boards for energy journals.



POWER to the People: Integrated Resource Planning in Developing Countries

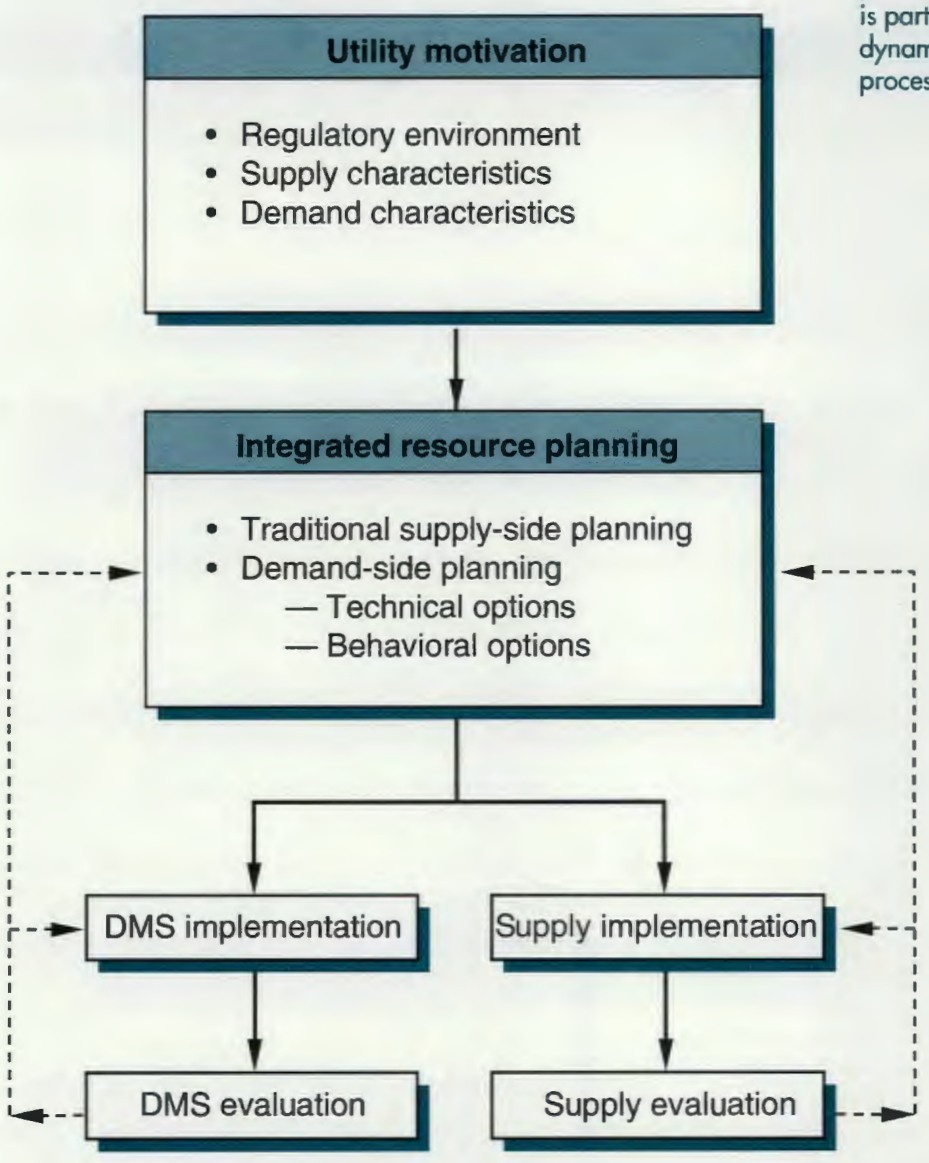
By Lawrence Hill

Increased burning of fossil fuels to meet the growing demand for electricity throughout the world could create havoc for our climate. Many argue that greenhouse gas emissions (primarily carbon dioxide) from producing electricity using fossil fuels contribute significantly to global warming. Over the past two decades, carbon emissions grew fastest in developing countries such as China, Brazil, South Korea, and India, primarily because of high growth rates in electricity production. From 1970 to the present, for example, carbon emissions increased by only 30% in the developed countries, while increasing by 80% in developing countries. ■ Scientists believe that using combinations of resources different from those used in the past to produce electricity—and integrating them in a cost-effective way—could ease the health, economic, and environmental effects of increased worldwide demand for electricity services. In developed countries, for example, electric utilities and energy planners have combined planning for electricity-capacity increases to meet growing demand with cost-effective reductions in the use of electricity.

Larry Hill is head of the Public Utility Studies Group in ORNL's Energy Division, which he joined in 1980. His group works on electric power issues for both domestic and foreign utilities. He is also a visiting fellow for the National Conference of State Legislatures in Denver, Colorado, where he works with state legislators and their staffs on issues and legislation associated with restructuring the U.S. electric power industry. He has a Ph.D. degree in economics from Indiana University.

Carbon emissions increased by only 30% in the developed countries, while increasing by 80% in developing countries.

Integrated resource planning is part of a dynamic process.



This combination reduces the total amount of electricity needed yet maintains the same level of electricity services. This planning process is called integrated resource planning (IRP).

The electricity planning problem in many developing countries is more complicated than in developed countries. The challenge is not only to substitute investment in cost-effective reductions in electricity use for investments in power plants as in developed countries but also to obtain financing for any electricity-related investment. Power development is difficult because electric power industries are among the most capital-intensive in an economy, draining scarce financial

resources. And, for countries lacking energy resources, importing oil and other fuels is also a major drain on foreign exchange reserves (the amount earned on exports minus the amount spent on imports).

The capital and foreign exchange required to develop modern electric power sectors, of course, compete with those same requirements in other sectors of the economy. That is, the electric power sector's drain on scarce capital and foreign exchange is exacerbated by the process of economic development itself: The transition from a self-sufficient, agriculturally based economy to a more specialized urban one requires capital and foreign exchange. Electric power is an important factor in this development process, fueling urbanization of an economy, its industrial growth, and rising standards of living.

Environmental problems, such as higher levels of carbon emissions that go along with economic development, further increase the complexity of electric-power decision making in developing countries. For example, the agreement at the United Nations Conference on Environment and Development in June 1992 that all countries should adopt programs to limit increases in greenhouse gas emissions is an example of an environmental obstacle to developing the power sectors of many developing countries.

IRP of the type practiced in developed countries is a management tool used to help reconcile power-sector capital and foreign-exchange requirements with the same requirements in the general economy and with the need to meet environmental regulations in producing electricity. Concisely, IRP is a tool that allows electric utilities to compare consistently the cost-effectiveness of all resource alternatives on both the demand and supply side, taking into account their different financial, environmental, and reliability characteristics. If applied properly, IRP leads to the most cost-effective electric-power resource mix, reducing the financial requirements to satisfy electric-power service needs. IRP is especially useful as a planning tool in growing economies that have increasing electric-generating capacity needs and, consequently, high power-supply costs.

IRP in Detail

In the IRP process, altering patterns and levels of electricity demand and constructing nontraditional generating plants (e.g., biofuel combustion) are weighed as resource options on an equal footing with traditional supply resources, such as building conventional fossil-fuel generating plants and extending the life of old ones. Or, alternatively, the IRP process is a combination of (1) traditional least-cost planning, a process by which utilities minimize the cost of generating a given amount of electricity, and (2) demand-side planning, a process by which utilities quantify and assess programs to alter the pattern and level of their customers' demand for electricity. The goal of IRP is to provide electricity at the lowest possible economic, social, and environmental cost.

Demand-side planning is part of a dynamic electric-utility planning process (as shown in the figure on p. 62). This process includes (1) motivating utilities to consider IRP, rather than using traditional methods of energy supply planning, (2) placing demand-side planning and supply-side planning on an equal basis in the planning process, and (3) implementing and evaluating the most cost-effective mix of demand and supply options. The process is dynamic not only because planning by its very nature is evolutionary but also, as shown in the figure, because the performance of demand-side management (DSM) programs and supply alternatives has feedback effects on both the process of selecting the programs and the way in which they are implemented.

The goal of IRP is to provide electricity at the lowest possible economic, social, and environmental cost.

Besides regulatory factors, characteristics of both a utility's supply system and customer demand influence the decision to engage in IRP. For example, the types of generating units used by electric utilities can be a motivating force to engage in IRP. If a utility relies on fossil-fuel units and fuel costs are rising, it may find IRP attractive. On the demand side, utilities with low load factors are more likely to seek ways to alter demand patterns to shave peak load (maximum daily demand for power) and forego the need to build peaking capacity. Several powerful tools

can accomplish changes in demand, including setting cost-based electricity prices—prices reflecting the actual costs of power used during different times of day. The goal in all cases is to find the mix of supply and demand resources that lowers present and future costs.

When comparing resource options in the IRP process, their varying characteristics complicate the process. That is, although DSM programs and supply resources have the common characteristic of meeting future energy and capacity requirements, they typically differ in reliability, cost, and economic impact, including considerations such as external costs (e.g., environmental degradation and injuries to workers) and the value of service.

We estimate that Hainan could cut as much as 80% of its 1992 peak electricity demand by 2000 by investing in cost-effective DSM programs.

The final two sets of blocks on implementation and evaluation in the figure are important. DSM programs are implemented and evaluated in the same way that supply resources are. That is, DSM programs are treated parallel to the manner in which a utility (1) chooses to build a power plant, (2) constructs it, and (3) evaluates its performance. The problem that many utilities in developing countries confront in treating DSM and supply resources in a parallel manner is the lack of data on running DSM programs. The technical savings of these programs are generally well known. Information on the marketing side is deficient; for example, the number of customers using different types of electricity-using equipment and the possible market penetration of energy-efficient equipment are not well known.

An IRP Example

China is a good example of a country in which IRP could make a difference by reconciling financial and environmental considerations in the power sector. National electric-power capacity in China is currently estimated to be 20% short of requirements, stifling economic development and growth. By 2000, authorities estimate that $100 billion will be required to construct needed generating capacity in an economy now growing at a rate of more than 10% per year.

As an indication of the potential of IRP to reduce the amount of funds required for the power sector in China, our group at ORNL applied IRP principles to the power sector in Hainan Province, China, one of the most rapidly developing areas in all of China. In 1988, Hainan Island off the southeast coast of China was separated from Guangdong Province, organized as a separate province, and designated China's fifth—and largest—special economic zone (SEZ). SEZs are areas designated to develop products to export as part of China's mixed development strategy.

In a prefeasibility study, we found that electricity savings from implementing DSM programs could be quite substantial. We estimate that Hainan could cut as much as 80% of its 1992 peak electricity demand by 2000 by investing in cost-effective DSM programs. Then we identified economically attractive, environmentally benign energy resources as alternatives to constructing coal-fired power plants in Hainan.

An important potential cost-effective source of savings is setting electricity prices that reflect the real costs of producing and distributing power during different hours of the day and days of the week. To varying degrees, many countries use electricity prices as an economic development tool. As a matter of policy, they set prices below costs to foster economic development, rather than at cost-based levels to reduce electricity demand. In the process, national governments subsidize electricity production. China is no exception. Changing these prices to reflect costs and, therefore, lowering the demand for electricity is an important alternative to constructing coal-fired power plants in Hainan. Also, cost-based pricing compares favorably with other technology-related DSM programs as alternatives to constructing generating plants.

Another cost-effective alternative to constructing power plants is to set more stringent standards to ensure construction of energy-efficient buildings in the three rapidly growing cities of Haikou, Sanya, and Yang Pu. These cities are currently experiencing a construction boom that is expected to continue. Therefore, now is a particularly favorable time to implement standards that require insulation, energy-efficient

windows, and other conservation measures for new commercial construction.

Hainan also appears to have the climate to support a cost-effective residential solar water heating program. A program to increase the penetration of efficient lighting in Hainan is also cost effective, resulting in significant demand-side electricity savings for the Hainan Electric Power Company while lowering energy costs for household customers.

Outlook

If the estimated savings in Hainan Province from using cost-effective resources other than power plants is indicative of the amount of savings possible in *all* Chinese provinces, the use of IRP as an electric-power planning tool has much to offer Chinese policymakers. First, China's economic modernization program would benefit; by identifying and acquiring cost-effective resources such as cost-based pricing, new building conservation standards, efficient lighting, and solar water heaters, Chinese policymakers will free funds for use in other parts of the economy. Second, China would slow its growth in greenhouse gas emissions by satisfying electricity service needs with resources other than power plants that burn fossil fuels. Clearly, integrated resource planning would be beneficial for not only the world's most populous nation but also the world. **ornl**

Modern, new buildings in Haikou, Hainan, the capital of Hainan Province, China, could be less costly to operate with improved building energy efficiency standards.

By Jim Pearce, Carolyn Krause, and Bill Cabage

The TRANSPORTATION REVOLUTION:

On Track for a Better Future?

Patricia Hu and Jennifer Young, both of ORNL's Center for Transportation Analysis, paint a foreboding picture of life on America's crowded highways. Their work shows that rush hour has become nearly an all-day affair, stretching from dawn until dusk, with only a brief midmorning lull.

Their report, based on a U.S. Department of Transportation survey of more than 21,000 households across the country, suggests a number of reasons for this trend. More drivers are driving more cars more often than ever before. More women are working outside the home, and more women are getting drivers' licenses. Teenagers are driving more too—nearly twice as much as they did in the 1960s. Even retirement-aged folks are getting in on the act, driving 40% more than they did 25 years ago.

And society itself is changing: Referring to urban sprawl, Hu says, "You can't really compare driving habits people had 30 years ago with the way we drive today. Thirty years ago, people could walk to the store, to school, even to work. Most of us can't do that anymore."

Carmakers and policymakers have been taking these trends into account for some time. So have scientists, who see technology as the source of solutions to the issues the travel boom has brought about—issues such as increases in traffic congestion, energy consumption, and emissions of pollutants that may threaten personal health and the global climate's stability.

When materials researcher Geoff Wood considers the range of transportation research going on in Oak Ridge, he sees practically unlimited potential. "We have tremendous opportunities in transportation research," he says, "particularly in the area of passenger cars, if we make the most of our resources." Lighter, stronger, and more durable materials, improved passenger safety systems, more efficient engines, cleaner burning fuels, and state-of-the-art manufacturing technologies are just some of the areas where Oak Ridge scientists are teaming up with researchers from U.S. industry to develop vehicles for the next century.

The transportation revolution that began almost a century ago with Ford's clattering Model T (and paved highways to drive it on) continues to transform our lives. In 1905, there were only 200,000 cars and trucks in the entire world; today there are 200 million automobiles in the United States alone, and the number grows daily. Although it has undoubtedly changed the world for the better, the transportation revolution also carries some heavy baggage—problems that threaten present and future generations' quality of life. For one thing, as vehicles consume more than 60% of our petroleum, they are responsible for more than 30% of the greenhouse gases produced in the United States. Gases emitted by cars and trucks can make the air we breathe unhealthy, may damage the ozone layer that protects us from ultraviolet light, and may eventually cause climate changes that could upset our economy and seriously restrict our standard of living. Regulated pollutants—nitrogen oxides, carbon monoxide, hydrocarbons, and particulates are known health hazards. There is also the possibility—or what many call the reality—that we will simply exhaust ready supplies of the petroleum fuels that power us down the pike.

To help solve these problems and help keep the revolution rolling without derailing the economies it has bolstered, ORNL has joined forces with other laboratories, corporations, and universities. In fact, transportation research in Oak Ridge is a $100-million-a-year business, bringing together world-class scientists with specialties from advanced materials to communications technologies to supercomputing. The goal is to keep people in the driver's seat of a transportation system that will carry us, as well as our children and grandchildren, through the next century.

ORNL Research in Transportation

ORNL is no stranger to transportation research, having laid much of the groundwork for nuclear-powered ships and submarines early in its history. The Laboratory has conducted extensive studies of the nation's transportation systems over the last two decades, and, most recently, developed the computer software systems that the U.S. military

One hundred years ago, only trees and maybe a few buildings would have occluded this sunset. Freeway horizons are now a common sight to commuters. The environmental effect of the increase in vehicle travel is the main driver of a strong and diverse research effort at ORNL.

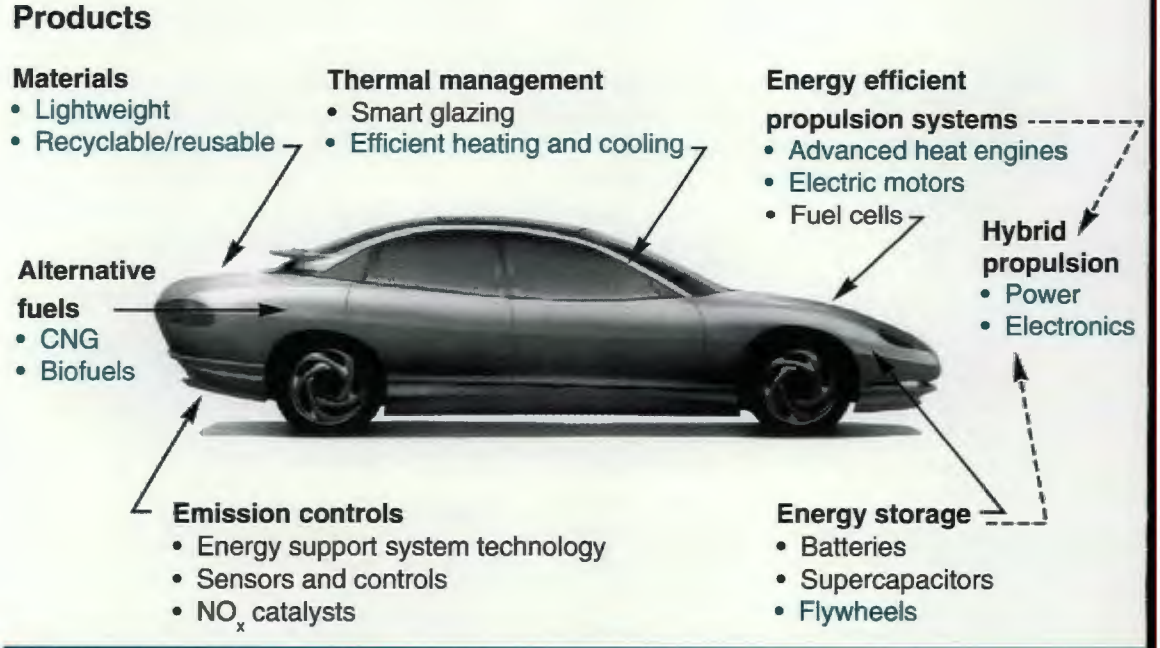
used to plan and schedule troop and supply transportation during the Persian Gulf War; in humanitarian relief missions to Somalia, Rwanda, and Zaire; and in peacekeeping missions in Haiti and Bosnia-Herzegovina. (See discussion of ADANS and JFAST on p. 69 of the *Review*, Vol. 28, No. 1, 1995.)

ORNL's Energy Division has compiled, analyzed, and published transportation data since the mid-1970s, soon after the first gas lines brought on by the 1973 oil embargo shocked Americans into new energy realities. Because the "energy crisis" had such widespread effects on the U.S. population and economy, the U.S. government took an active role in addressing the problems in energy-related areas. That government role has coincided with ORNL's growing involvement with energy and environmental research over the past two decades, including studies of the effects of the increasing amount of carbon dioxide in the atmosphere, to which crowded highways contribute their share.

In the 1990s the U.S. government launched two programs involving government, industry, and universities. One is the Partnership for a New Generation of Vehicles (PNGV). The other, the Intelligent Transportation System (ITS), would produce "smart" cars and highways from a marriage between the automobile and the computer.

The chief goals of smart cars and ITS, which until recently was referred to as the Intelligent Vehicle Highway System, are safer and more efficient means of "getting there." Three goals drive the PNGV: One is to improve manufacturing technology, which includes using supercomputers to reduce the cost of developing and fabricating new products. The second is to provide near-term improvements to current vehicles, such as improving and reducing the cost of catalytic

The chief goals of smart cars and highways are safer and more efficient means of "getting there."



ORNL's contributions to the Clean Car Initiative are highlighted in color.

converters and developing a lean-burn engine—one that uses more air and less fuel. Third is the magic formula: achieve three times the fuel economy without giving up comfort or performance, at an affordable price.

Today Laboratory researchers are attacking the transportation problem on many fronts through partnerships with others in academia, industry, and government. The Partnership for a New Generation of Vehicles involves several federal agencies, including DOE, that have teamed up with the "Big Three" automakers—General Motors, Ford, and Chrysler—to rethink what vehicles will need to be and do in the next century. This partnership is developing technologies to make a new generation of highly efficient, safe, reliable, and environmentally friendly cars. The ultimate goal of this initiative is an affordable midsize car that gets 80 miles to the gallon and emits significantly less pollution.

Toward this goal, ORNL researchers have characterized and guided development of ceramics and metal alloys for high-temperature engines that run both cleaner and leaner. They have worked with industry to develop advanced piston engines and automotive gas turbines to improve efficiency and reduce emissions (see the sidebar "Ceramic Parts for Autos" on p. 72). They have developed ways to raise the efficiency of car air conditioners to improve fuel economy and reduce emissions of greenhouse gases (see liquid overfeed air conditioner sidebar on p. 70). Researchers are also evaluating use of lighter-weight structural materials in cars and aircraft—aluminum, magnesium, and plastics—to improve fuel efficiency and reduce greenhouse gas emissions.

ORNL researchers are using massively parallel supercomputers to improve the design, manufacture, and fuel combustion efficiency of future vehicles. They are using supercomputers to simulate car crashes and assess the effect lighter vehicle materials may have on a vehicle's ability to absorb energy and maintain passenger safety. They are providing flywheel and power electronics technology to an industry team developing a "hybrid vehicle" powered by gasoline and electricity. They are helping automotive suppliers use advanced manufacturing techniques. They are identifying fast-growing trees and grasses that can be converted to alternative fuels such as ethanol.

As more and more traffic clogs our highways, ORNL is working to unlock gridlock by helping to develop smart-car technologies. Part of the solution is evolution—adapting our current transportation system to the demands of a new century. ORNL researchers are developing on-board traveler information displays, collecting data for the design of crash avoidance systems, and evaluating "smart" cars that converse with central control computers about road conditions, safety concerns, and the fastest way to get from point A to point B. These developments won't just help Joe Commuter get to work on time—they'll also help travelers avoid traffic congestion in places like Atlanta, Georgia, during the 1996 Summer Olympic Games.

High in Efficiency, Low in Emissions

The PNGV, sometimes called the Supercar Initiative, is "one of the federal government's premiere ventures into cooperative civilian technology development," said John H. Gibbons, President Clinton's science adviser and a former ORNL physicist, in a speech to Congress last year. "In it, we are tackling a technological challenge as tough as putting a man on the moon—that is, to develop within 10 years a car with three times the efficiency of today's automobiles with no sacrifice in cost, comfort, or safety. If the project succeeds, the payoff to the public will be huge in terms of less dependence on foreign oil and lower emissions. The project also holds the promise of an extremely attractive car for world markets in the 21st century and a thriving U.S. auto industry to produce them."

Most vehicles use gasoline or diesel fuel, which are made from petroleum. The United States now imports close to half (45%) of its petroleum. Reducing its dependence on foreign oil would help the United States improve its trade imbalance and ensure secure energy supplies. From a global

The ultimate goal ...is an affordable midsize car that gets 80 miles to the gallon and emits...less pollution.

Reducing the Comfort Penalty: Liquid-Overfeed Air Conditioner

Reducing the comfort penalty: researchers Fang Chen and Vince Mei in ORNL's Energy Division have invented the liquid-overfeed air conditioner, which may help bring electric hybrid vehicles to the mass market sooner.

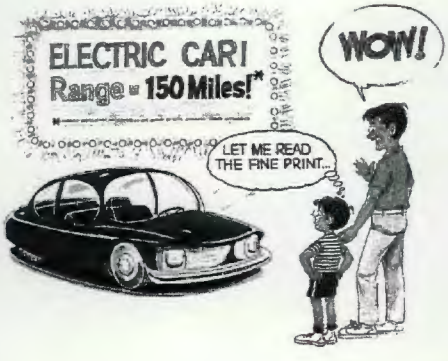
Automobiles without air conditioners are more the exception than the rule nowadays. To many, a summer of driving without A/C is unthinkable. Air conditioners even play a role in winter driving—they make defrosters work better, for instance. But air conditioners also reduce engine performance and diminish fuel economy, especially in smaller cars.

That comfort penalty grows in importance when it is factored into efforts to improve fuel economy and range for new automobile technologies such as hybrid vehicles. Fang Chen and Vince Mei, researchers in the Energy Division, found a way to reduce the comfort penalty. They devised a recuperative heat exchange concept and adapted it to the cooling cycle of an automotive air conditioner, resulting in a substantial improvement in its efficiency.

Their invention, called the liquid-overfeed air conditioner system, is essentially an additional heat-exchanger loop that overfeeds refrigerant through the system's evaporator, increasing its cooling capacity. Excess liquid leaving the evaporator is routed to the heat exchanger, protecting the unit's compressor and decreasing its work load, which in turn lessens the load on the engine, which must power the compressor as well as the drive train when the A/C is on.

The environmentally mandated shift to refrigerants that don't contain chlorofluorocarbon (CFC) refrigerants has increased interest in their work because most of the non-CFC refrigerants don't cool as effectively as CFCs. "We're trying to find ways to improve efficiency in air conditioners," Chen says. "We're also studying the thermodynamic cycle to find ways to counteract the drop in efficiency encountered with non-CFC refrigerants."

If automakers do become interested in modifying their cooling system designs to include the liquid-overfeed heat exchanger, the task shouldn't be too difficult because the device doesn't take up much space and is put together from readily available components. Some automobiles already have an accumulator in their cooling systems; adding the liquid-overfeed feature would be a simple matter.



Currently, environmental damage (ozone depletion and global warming) caused by refrigerant leakages from automobile air conditioners receive more attention than concern over energy efficiency. Chen, however, points to an energy cost that is greater than it appears on the surface. If a car has 100 horsepower, as many do, the five-horsepower cost in engine power for running the air conditioner doesn't seem that great. However, the same car at cruising speed requires only 25 horsepower at the most. Then, relatively speaking, that five horsepower represents a much larger demand on the engine.

Energy-efficient mobile air conditioning will become more important for electric as well as hybrid vehicles, Chen says, explaining that every kilowatt-hour of battery energy used by air conditioning is one less kilowatt-hour to power the electric vehicle. Operating an air conditioner would drop the 75- to 100-miles-per-recharge range of an electric vehicle considerably, putting its feasibility in question.

As designers face those restrictions, the liquid overfeed system has attracted notice in the field: It won this year's Inventors Club of America's International Hall of Fame Award. More recently, the liquid overfeed air conditioner was part of a winning University of Tennessee (UT) entry in the 1995 Hybrid Electric Vehicle Challenge at Auburn Hills, Michigan. The 1995 Chrysler Neon that a group of UT engineering students modified to run on alternate fuels was tested in the Large-Scale Climate Simulator at ORNL's Buildings Technology Center.

It has been estimated that if the liquid overfeed technology were fully implemented by U.S. automakers, the device could save 340 million gallons of fuel per year, cut carbon dioxide emissions, and reduce the consumer's cost of driving. The system could also help extend the range of the hybrid-electric vehicle, bringing it closer to the marketplace.

—Bill Caba

point of view, petroleum is a fossil energy source that may be depleted before the end of the next century because less developed countries are buying and using increasing numbers of vehicles as their economies grow. Thus, the need for fuel-efficient vehicles takes on new importance to slow the increase in emissions and delay the depletion of the world's oil supply.

Bob Honea, director of the Center for Cooperative Transportation Research, says, "There is a potentially tremendous demand for vehicles, particularly in Asia and the developing countries, that could overwhelm the world's oil reserves. Current estimates by the petroleum industry itself predict that the world's oil supplies will be gone in 45 to 55 years. To head off that scenario, we need a vehicle that is both affordable and safe and either extremely fuel efficient or fueled by an alternative energy source."

(Currently, more than 60,000 vehicles in the United States operate on compressed natural gas even though only 1200 natural gas filling stations are available. By 1997, DOE plans to put 250,000 alternative fuel vehicles in government fleets. These trends are driven by the 1990 Clean Air Act and the 1992 Energy Policy Act.)

The most favored approach to automotive efficiency is a hybrid vehicle powered by both fuel and electricity. Cars and trucks would be equipped with high-speed flywheels, batteries, or ultracapacitors that store energy accumulated while cruising downhill. Electric motors working in reverse (as generators) would recover energy lost in braking. Flywheels would supplement a small, fuel-powered engine for accelerating the vehicle. Because they spin at thousands of revolutions per second, flywheels store a

(Continued on p. 74.)

Mark Valk, a University of Tennessee senior mechanical engineering student, prepares a 1995 Chrysler Neon for a test in the Large Scale Climate Simulator at ORNL's Buildings Technology Center. This hybrid electric vehicle placed first in its category in the 1995 Hybrid Electric Vehicle Challenge held in June 1995 in Auburn Hills, Michigan.

Ceramic Parts for Autos: ORNL's Role

Each year, motor vehicles in the United States release about 350 million tons of carbon into the atmosphere in the form of carbon monoxide and carbon dioxide. To reduce these emissions significantly, a radically different propulsion system is needed.

Scientists and engineers working with the PNGV see the hybrid vehicle as the most likely track for the car of the future. Energy for the hybrid vehicle would be stored by advanced batteries, flywheels, or ultracapacitors. Power source candidates for the hybrid include small diesel engines, fuel cells similar to those that power spacecraft, and gas turbines.

Technologies that would enable the hybrid to run efficiently and reliably are largely dependent on how successful science and industry are at developing new materials, including ceramic materials. A hybrid electric vehicle with a gas turbine engine, compared with spark ignition engines widely used today, would weigh less, last longer, be more fuel-efficient, could burn a variety of fuels, and would have lower emissions of nitrogen oxides and carbon gases.

Today, however, gas turbines fit into few hybrid car schemes because of other technical problems. For one thing, small gas turbines that might be used in a hybrid vehicle must operate at elevated temperatures to achieve the needed high efficiency. It is not practical to cool small turbines because the components would have to be very small compared to the size of the cooling passages. Even the most advanced superalloys do not have sufficient high-temperature strength and fatigue resistance at the required temperatures. The gas turbine is a good example of the need to develop reliable, low-cost ceramic or fiber-reinforced composite components, including turbine blades, vanes, scrolls, and combustors.

In 1983 DOE Energy Efficiency and Renewable Energy's Office of Transportation Technologies started the Ceramic Technology Project. ORNL was asked to carry out technical management of the project, whose goal was to involve industry in developing technology to make reliable ceramics, advanced processing technology to minimize the number and size of flaws in ceramics, and new methods to test the mechanical behavior of ceramics to more accurately predict how long they will hold up before failing under conditions typical of high-temperature engines.

AlliedSignal Ceramic Components fabricated this turbine rotor from silicon nitride using ORNL's gelcasting technology.

Since that time, the ceramics and automobile industries have been developing and testing ceramic parts. Nissan introduced silicon nitride ceramic turbochargers in 1985, suggesting that it is feasible to economically mass produce gas turbine engines. In the DOE-NASA Advanced Turbine Technology Applications Program, the General Motors Allison Turbine Division ran silicon nitride turbine rotors for 1000 hours in a simulated driving cycle that went up to full speed at 1370°C (2500°F).

What were the achievements of the Ceramic Technology Project? According to D. Ray Johnson, project leader in ORNL's Metals and Ceramics Division: "In assessing the needs of the automobile industry, we found that increased reliability of ceramic materials was necessary. So the project developed silicon nitride ceramics that were highly reliable, including manufacturing processes to

eliminate the sources of flaws that had limited the strength of silicon nitride. For example, it was found that growing elongated silicon nitride grains that behave like whiskers in the ceramic itself greatly improved its toughness and reduced its tendency to form cracks even if flaws were present. Our researchers also developed better ways to test the mechanical strength of ceramics and accurately predict the lifetime of ceramic components under a given set of conditions."

After the first ten years of the Ceramic Technology Project, it was time to shift gears. "During our recent visits to automobile and engine companies," Johnson says, "we were told that ceramics can now run reliably in conventional automotive engines, but they 'cost too much' to be used for production." Realizing that ceramic components must be competitive in price with metal components in the cost-conscious auto industry, the direction of the Ceramic Technology Project shifted toward reducing the cost of ceramics and finding ways to mass produce reliable ceramic parts for the auto industry economically.

Johnson says that in 1993 DOE introduced a ceramic manufacturing initiative to bring the automotive and ceramic industries together with government researchers to solve manufacturing problems. One result of the cost-effective ceramics initiative was the development of a Ceramic Manufacturability Center at ORNL's High Temperature Materials Laboratory for users from government and industry.

ORNL researchers have made invaluable contributions to the program through their research and development work, as well as through their guidance of research performed in industrial and university laboratories. "We are using the computer to model the costs of ceramic manufacturing to determine ways to bring down the cost," Johnson says. "It turns out that ceramic machining can contribute more than half the total cost of a ceramic component. So, we are looking at alternatives to diamond machining and other processes for cutting, shaping, and finishing ceramics to reduce costs. We are trying to find more economic ways of synthesizing silicon nitride powders and forming and densifying ceramics. Gelcasting is a candidate method for forming ceramics because it improves precision of shapes and minimizes the need for finish machining."

Gelcasting, an advanced forming method for ceramics, was invented in 1987 by Mark A. Janney and Ogbemi O. Omatete, both of ORNL's Metals and Ceramics Division. It allows a ceramic part to be machined before, not after, the part is heated to make it hard. AlliedSignal Ceramic Components and other companies are interested in using the technology for manufacturing airplane and automobile engine parts that are light and resistant to corrosion and high temperatures. Gelcasting has been patented and licensed to two companies. In addition, with contributions by Stephen Nunn and Claudia Walls, gelcasting received an R&D 100 award in 1995.

Other ceramic technologies developed at ORNL include self-aligning grips for tensile testing of ceramics, invented by Kenneth C. Liu, licensed to Instron Corporation, and sold to laboratories all over the world. A method of producing low-cost silicon nitride ceramics by microwave processing has been developed by Terry N. Tiegs, James O. Kiggans, and colleagues. That technology, which produces ceramics that resist fracturing and thermal shock, also does the job at a price competitive with metal components, making it very promising as a method of mass-producing automotive ceramic components.

ORNL researchers have made substantial contributions to the development of tougher ceramics, protective coatings for ceramics, and low-expansion ceramics; joining of ceramics to metals; ceramic machining; analytical electron microscopy of ceramics; nondestructive evaluation of ceramics; characterization of mechanical behavior of ceramics; development of a computer database of mechanical properties, and participation in an international effort to develop standards for ceramics.

"Another goal is to pave the way for an automated, intelligent manufacturing plant," Johnson says. "Industrial researchers are developing intelligent, computer-controlled processes that use robotics to handle materials and sensors to determine product quality on-line. The expected results are an increase in the reliability of structural ceramics and lowered manufacturing costs for ceramic auto parts."

If the cars of the future are made of these advanced materials, advances will likely be made in reducing use of fuel and the release of carbon dioxide to the air.

—Carolyn Krause

The direction of the Ceramic Technology Project shifted toward ... finding ways to economically mass produce reliable ceramic parts for the auto industry.

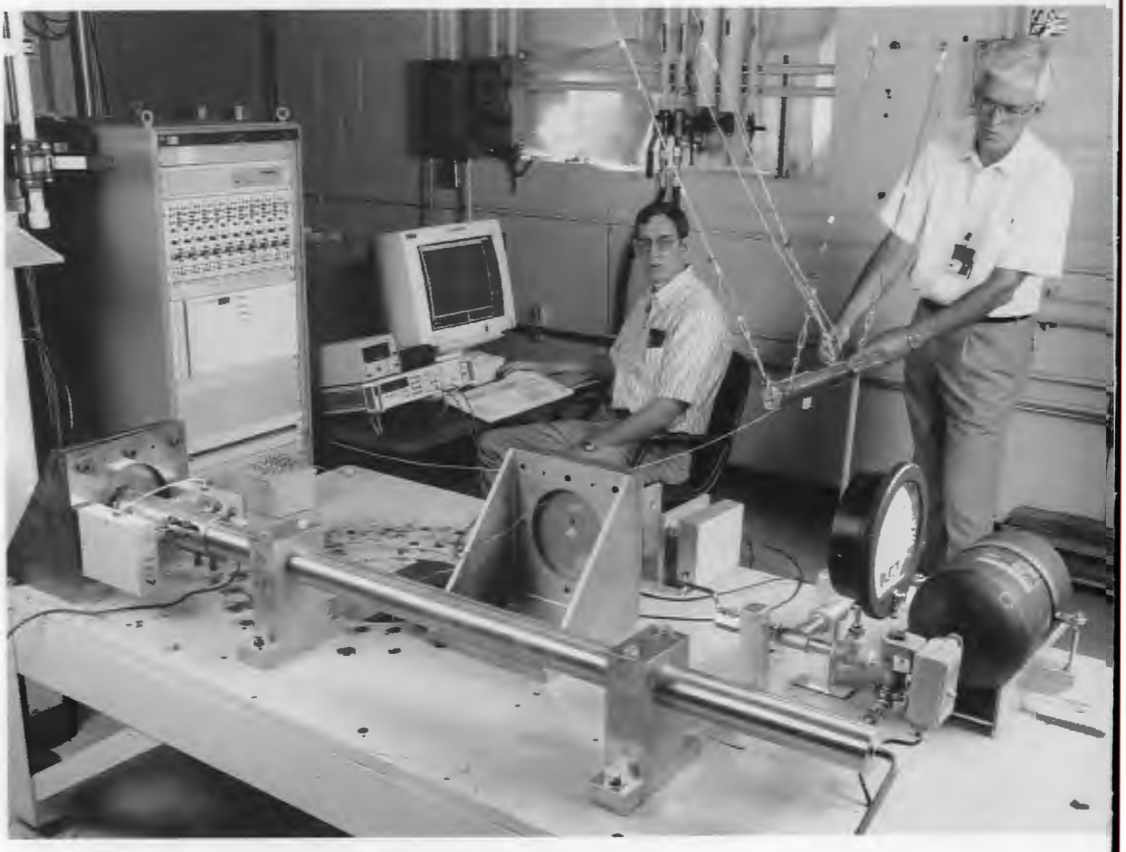
considerable amount of energy—a reserve that can be called on when a little extra push is needed for passing or climbing a steep hill.

The hybrid strategy results from the realization by PNGV planners that reaching the goals set forward for the clean car—including the 80 mpg milestone— will require major advances in a number of technologies. Several of these technologies—gas turbines, flywheels, advanced batteries, and lightweight materials, for instance—have been actively pursued at ORNL over the years, many in programs not directly related to commercial transportation. The hybrid's appetite for technology instead of fuel may prove to be very well suited to ORNL's multidisciplinary scope of research.

ORNL's Buildings Technology Center was recently used for a test of a 1995 Chrysler Neon that was converted to a hybrid electric vehicle by Professor Jeffrey Hodgson and his mechanical engineering students at the University of Tennessee at Knoxville. ORNL tested how fast the car's heat pump warmed the passenger cabin during simulated winter conditions. The car placed first in its category in the 1995 Hybrid Electric Vehicle Challenge held in June 1995 in Auburn Hills, Michigan. The car uses computer controls to coordinate the parallel operation of the engine, which is fueled by natural gas, and the electric motor (powered by a rechargeable battery) to drive the wheels. The success of the competition suggests that future drivers may someday go to service stations not only to fill 'er up but also to plug 'er in.

What is ORNL doing to help develop a fuel-efficient, clean-running vehicle that is also safe and affordable?

One way to increase fuel efficiency in vehicles and reduce exhaust emissions is to build them from lightweight materials, such as aluminum, magnesium, and polymer matrix composites (PMCs)—high-strength plastics that are similar to



Lightweight composite automotive body structures of the future will have to withstand the effects of low-energy impacts, such as tool drops and roadway gravel kickups, without significant damage. Here, Rick Battiste (left) and Jim Corum subject instrumented composite plaques to pendulum drop impacts (representing tool drops) and projectile impacts from a gas gun (representing roadway kickups).

fiberglass. Auto components targeted by ORNL studies are steering mechanisms, suspension systems, valves, structural components, and body parts such as hoods, roofs, and doors. The goal is to fabricate cars that are 40% lighter than today's cars by using steel substitutes; a 10% reduction in a vehicle's mass increases fuel economy by up to 6%.

You can't simply substitute for a material like steel by making the same component out of aluminum," says Phil Sklad of the Metals and Ceramics (M&C) Division. "You have to compensate and make design changes to take advantage of aluminum's unique properties so that the component works as well as the steel counterpart."

One concern is passenger safety in vehicles made of lightweight materials. These vehicles must be designed so that lightweight materials will absorb energy as well as or better than steel during collisions. Another concern is affordability. The costs of the materials and the processes for manufacturing vehicle components must be competitive with steel.

To help meet these goals, ORNL is involved in several cooperative research and development agreements (CRADAs) with the U.S. Automotive Materials Partnership. One CRADA involves a study of the use of adhesives, rather than fasteners and welds, to join materials such as aluminum to steel or PMCs to aluminum. "Because adhesives are a different joining technique, they will affect how energy is absorbed by the vehicle under different impacts," Sklad says. "Computer models of a car's energy-absorption ability must take into account the role of adhesives."

Many automobile parts are made by forging—forming a hot metal into desirable shapes by compressing it. To reduce manufacturing costs, another CRADA in which ORNL is involved is examining casting, which is less expensive than forging. Casting involves pouring a liquid metal into a mold and letting it solidify into the desired shape.

"The molded part must have certain properties," Sklad says. "These properties are related to certain microstructures which can be attained if casting conditions are properly controlled. Casting conditions include temperature of the liquid, pouring speed, mold design, and solidification rate. If these conditions are not right, the product will contain defects such as pores that can lead to cracking. We are trying to determine how parameters in the casting process should be controlled to achieve the desired microstructure and properties."

Jim Corum of ORNL's Engineering Technology Division is testing the durability of polymer matrix composites that are candidates for structural components of cars. PMCs are matted fibers held together by a resin. The fibers provide strength to the material, but they can break, weakening the component.

"What happens to the material if an auto worker drops a wrench on it or if a stone is kicked up into it by a moving car or if oil or windshield wiper fluid spills on it?" Sklad asks. "Corum is characterizing PMC samples, exposing them in test rigs to impacts and various auto fluids, and characterizing them again to see how much they degrade."

The High Temperature Materials Laboratory, where much transportation-related research is conducted, was built soon after work began on ceramic materials for automotive gas turbines and low heat rejection diesels in 1983. This jewel in ORNL's crown was made possible by DOE's renewed interest in developing highly efficient and cleaner-running engines for automobiles. These engines—gas turbines and diesel engines for cars and trucks—would operate at temperatures high enough to weaken metals used in internal combustion engines; thus, research was needed on how to form reliable engine parts from ceramics, ceramic-metal composites, and high-temperature alloys—materials that can withstand the higher temperatures needed to extract more energy from fuel and release less pollution. Thus, DOE supported efforts at ORNL and elsewhere to guide industry in developing reliable ceramic and nickel-based components for high-temperature engines and to develop low-cost methods of manufacturing these engine parts.

One of these promising materials is silicon nitride, the preferred material for components of gas turbines because it is strong, hard, and

One way to increase fuel efficiency in vehicles and reduce exhaust emissions is to build them from lightweight materials.

Our vehicles... are the source of almost one-third of the carbon dioxide emissions to the atmosphere in the United States.

resistant to wear, oxidation, decomposition, and thermal shock at very high temperatures. Researchers in ORNL's M&C Division have contributed to the industrial development of silicon nitride ceramics that can be shaped into reliable engine parts at high temperatures. Their characterization and analysis of the microstructure of various ceramics have steered industrial firms into selecting the most promising types of silicon nitride and modifying their chemistry to make them fabricable and reliable. Silicon nitride parts are being used in high-wear parts and valve train components in large diesel engines. Researchers in the HTML are also proving that ceramics can be inexpensively milled and machined.

Now, about the air that we breathe. Our vehicles—especially cars, trucks, and aircraft—are the source of almost one-third of the carbon dioxide emissions to the atmosphere in the United States; that's a problem because increased atmospheric concentrations of carbon dioxide (and other greenhouse gases such as methane, nitrogen oxide, and chlorofluorocarbons) could alter the climate in undesirable ways. Transportation is a significant source of this greenhouse gas because more than 99% of the energy used for transportation in our country comes directly or indirectly from carbon-based fossil fuels—mainly petroleum and natural gas. Motor vehicles also emit nitrogen oxides, hydrocarbons, and other pollutants that make urban air unhealthy.

How is ORNL contributing to the development of a clean car in the literal sense—one that emits virtually no pollutants and greenhouse gases? For the long term, ORNL's work in developing reliable, low-cost ceramic parts should hasten the manufacture of vehicles by the automobile industry that make use of technologies like gas turbines. For the short term, Ron Graves and his group in the Engineering Technology Division have been working with GM, Ford, and Chrysler engineers on a project to clean up current and near-term automobile engines by developing more effective catalysts that remove pollutants from the exhaust. New catalysts would be needed for the "lean burn" engine, a fuel-sipping design that runs at cooler temperatures. The catalysts currently used require high temperatures; with a lean-burn engine, they wouldn't pass emissions tests. Research toward more advanced catalysts and other projects like it can begin to protect the environment now, while cleaner, more-efficient propulsion alternatives are being developed.

Efficient Manufacturing of Efficient Automobiles

Today, increasing emphasis is being placed on developing efficient manufacturing processes for the automobile industry. More efficient manufacturing processes are needed to put more-efficient vehicles on the highways. One ORNL manufacturing technology that has attracted the interest of carmakers is also the subject of the CRADA called "Predictive Model and Methodology for Heat Treat Distortion." Its objective is to put technologies that the Oak Ridge Y-12 Plant has developed—originally in working with uranium—on the auto factory shop floor.

During the heat-treat process and subsequent cooling or quenching, metal parts, especially the teeth of gears, are subject to distortion. If it's severe enough, the part must be reworked, and that's expensive. In the 1980s, a team of researchers led by Gerard Ludtka, then in Y-12's Development Division and now in the M&C Division, developed a method of predicting distortion caused by heat treating by measuring the material and cooling parameters that govern the process. They applied the "Quench Simulator" model to uranium alloy pieces; ORNL and independent lab tests verified the accuracy of the model's predictions. That work was cited in 1995 when Ludtka received the E. O. Lawrence Award for materials science.

The cooling parameters yielded by the Quench Simulator are of obvious interest to the auto industry. The heat-treat distortion CRADA researchers will measure the properties of steels used for automotive gears and incorporate the information into the Quench Simulator model. According to Jim Park of ORNL's Computational Physics and Engineering Division, designers will start out knowing the materials they want to use

and then rely on the model to fabricate the part in a way that allows for the heat-treat distortions. "In many cases," Park says, "they might start out with a part that appears to be out of specifications, but conforms after heat treating." Participants in the CRADA include General Motors, Ford Motor Company, the Torrington Company, the U.S. Army, and Illinois Institute of Technology as well as ORNL, Sandia National Laboratories, Los Alamos National Laboratory, and Lawrence Livermore National Laboratory. The CRADA is managed by the National Center for Manufacturing Sciences in Ann Arbor, Michigan.

In another development that promises to pay dividends in the factory, a U.S. car manufacturer (General Motors) has found that ORNL's modified nickel aluminide is more resistant to cracking than the material now being used for heat-treating trays in furnaces. According to Vinod Sikka in the M&C Division, nickel aluminide is not affected by exposure to oxygen and carbon, and thus is more durable in those high-temperature environments. These trays hold automobile parts—valves, ball bearings, and gears—that are hardened (to make them resistant to wear) by heating them in a carbon atmosphere. Longer-lasting nickel aluminide furnace components could save the company a considerable sum of money.

For materials researcher Geoff Wood, one of the keys to reaching ORNL's potential in transportation research is the Oak Ridge Centers for Manufacturing Technology, which could help clear a middle ground between the drawing board and the marketplace, enabling industry to explore the potential of new products and technologies more completely.

"These projects are working within a long time frame," Wood says. "For example, the auto companies would like to develop a process that would allow them to efficiently assemble the entire structure of a car—chassis, body panels, and so on—out of only six to ten composite pieces."

The challenge facing Wood and his colleagues isn't just how to make a car out of a half dozen or so pieces of polymer-matrix composite components. It's how to turn them out fast enough to match the industry's production line rate. That means figuring out how to make a part out of fibers and liquid resin and get it onto the assembly line in less than 5 minutes.

"The four basic steps in this process,"says Wood, "are loading the mold with fibers, injecting the resin, allowing the panel to harden, and removing it from the mold. The curing and removing steps aren't a big concern at this point. The areas we need to work on are creating and loading the fiber preform and injecting the resin.

"The first step is packing the fibers into the preform. Right now, this takes on the order of 5 minutes. Once the mold is loaded, we inject the resin—that's what holds all the fibers together. It's important that the resin completely saturates all of the fibers in the preform because the bonding between the fibers and the resin provides the strength of the vehicle. Pumping the resin into a thin mold that is tightly packed with fibers can take up to about 5 minutes. We're working on ways of reducing that to a half minute or so."

Of course, 5 minutes here and 5 minutes there begins to add up, particularly for a group aiming to put a part on the assembly line in under 5 minutes. However, says Wood, "These two processes are usually done in parallel—someone is filling molds with fiber on one machine while someone else is injecting them with resin on another. We'll meet the industry's goal—it's just a matter of time. We're down to 8 or 10 minutes for the whole process now."

In the past, Wood notes, transportation research projects were sponsored by a number of different groups that didn't talk to each other much. Now the U.S. automotive industry is becoming more focused and beginning to speak with one voice. "All the major components of any transportation system—materials, propulsion, and fuels—are here. Now that we're all working toward a common goal, progress can be made much more quickly."

The auto companies would like to develop a process that would allow them to efficiently assemble the entire structure of a car.

Modeling Future Car Models

Dick Ziegler, manager of ORNL's Advanced Automotive Technology Program, recently spent a

The idea is to crunch numbers, not cars, to get the answer. This alternative has turned out to be considerably cheaper than crash-testing.

year in ORNL's Washington, D.C., office doing what he could to "make it happen" for the Partnership for a New Generation of Vehicles. Before that, he helped guide the Lightweight Materials Program through the early stages of its collaboration with industry. The automakers had already made huge investments in developing new materials for lighter, more-efficient autos. The hangup, the ORNL group found, was that a lack of knowledge of how these new materials performed during production was slowing their implementation. The manufacturers had lots of experience in forming steel, but more exotic alloys were uncharted territory.

"The automakers identified material performance modeling and process modeling as critical needs to allow them to determine, without many years of testing, how to design and produce cars with new, different materials," Ziegler said. In other words, if a car door is stamped out of a new alloy, will it spring back into a shape within specifications? Trial and error production is too costly for the car business.

"All of this must be known four to five years prior to new model introduction, and little or no risk can be taken in light of the severe consequences of failure," Ziegler said. ORNL's computer modeling could give the industry helpful information on crash effects, weight minimization, tool design and limitations, durability, and finished costs. "We are helping in ways that may be too costly or risky for them to do," he said.

In 1992 ORNL hosted an industry workshop that identifed a wide range of material and process interests in the industries. Those processes focused on forming, joining, alloy development, and finishing technology for high-strength steel, aluminum, and magnesium. Because of the automobile industry's raw material and production costs, ultralight vehicles are years away. New materials, fabrication processes, and knowledge are required to make it a reality. ORNL's best contributions may be through its materials development and computer modeling capabilities.

In addition to predicting how new materials will adapt to manufacturing, ORNL's supercomputers—primarily the Intel Paragon XP/S 150—are also being used for tasks such as modeling combustion processes in automobiles. Perhaps the most visually stimulating work has been produced when the Paragon is used to predict how cars behave when they slam into each other or into other objects.

Describing work being done by Srdan Simunovic of the M&C Division, Thomas Zacharia leafs through computer-generated images of a Ford Taurus colliding with a telephone pole. "You see these areas here and here," he says, pointing to crushed areas between the car's engine and front bumper. "These are crumple zones. Each time you crumple something you absorb some of the force of the impact, so less force is transferred to the passengers."

Not too long ago, solving design and manufacturing problems was a matter of trial and error. Car designs were tested by crashing specially built and instrumented cars into obstacles and studying the results. This was not only expensive—about a million dollars per crash—but it was also time-consuming. It took months to thoroughly test a design—inevitably increasing the time it took to get new products to market. In the last few years, however, supercomputers have shouldered much of this load by providing detailed computer models of collisions. The idea is to crunch numbers, not cars, to get the answer. This alternative has turned out to be considerably cheaper than crash-testing, but, until recently, it still took 6 weeks to simulate a single crash on a conventional Cray supercomputer.

"Today," Zacharia says, "a single set of analyses takes a few days to a few weeks on standard supercomputers. Using parallel supercomputing technology, we're working on bringing that down to a few hours. Calculations that used to take 48 hours, we can do in 2, and we're well on our way to doing it in minutes."

Instead of using a single microprocessor, or "brain," to solve a problem one step at a time, parallel supercomputers use hundreds or even thousands of smaller brains to break a problem into pieces and solve them all at once.

"We're one of the few groups in the country putting together high-performance parallel computers with manufacturing sector applications," says Zacharia, who originally headed up ORNL's effort to apply supercomputing to automotive design. Using the Intel Paragon XP/S 150 supercomputer, a half-dozen crash scenarios can be modeled at once, in hours instead of days or weeks, helping designers to explore a range of alternatives to optimize the use of lightweight materials.

"Modeling on the parallel computer not only promises to combine the advantages of new lightweight materials with the safety of today's vehicles," says Zacharia, "but it should also knock weeks off overall vehicle development time." This head start helps get new designs off the drawing board and on the market sooner and for less money—and gives U.S. auto manufacturers a jump on the competition.

Our National Traffic Jam

Efficient cars stalled in heavy traffic lose their efficiency. They burn more fuel and pollute more than they should. How bad has traffic congestion in America become?

As described at the beginning of this article, ORNL Center for Transportation Analysis researchers Patricia Hu and Jennifer Young gather statistics that tell of a day-long urban traffic jam where pedestrians have become about as obsolete as the horse. They published their analysis of findings from a U.S. Department of Transportation (DOT) survey in the *1990 Nationwide Personal Transportation Survey*. DOT collected data for a 1995 study, Hu says, and she's pretty confident that the number of cars and drivers on the road will show a continued increase.

Hu and Young's report brings to the surface a number of interesting developments in the activities of American drivers, and in American culture itself. The rate of increase in the number of U.S. licensed drivers from 1983 to 1990, for instance, was double the rate of population growth. The high rate is attributed to more women in the work force and more women who drive. The surge in traffic between the morning and afternoon rush hours, Hu says, is partly the result of an aging population—out in the noonday sun to avoid the rush hours. These same retirees have driven all their lives and have seen American culture become centered largely around the automobile. They've seen the corner grocery and hardware stores virtually disappear, replaced by superstores almost inaccessible to the foot traveler.

In the face of a never-ending rush hour, rising gasoline taxes, and a growing hole in the planet's ozone layer, you'd think the public would be clamoring for greater access to transportation alternatives, such as buses and trains. "We asked people about that," says Hu. "They'd still rather use their cars—it's more convenient."

Traffic is already unacceptably clogged in many U.S. cities, although devoting land and resources to building new highways is increasingly difficult. Adding one lane of interstate highway can cost $30 million per mile in an urban area and $10 million in the country. As a result of the increased number of vehicles on the highway, roads and bridges are deteriorating fast, energy and time are wasted, more carbon dioxide and pollutants are needlessly discharged to the air, and more accidents occur, causing property damage, injuries, and deaths. Mishaps kill 40,000 Americans a year; property losses cost $350 billion a year. Overall, a dilapidated highway system jammed with traffic could ultimately stall economic growth and curb U.S. competitiveness.

"We see three primary consequences of increased travel," Hu said. "They are more air pollution, more congestion, and more demand for imported oil, which threatens our national energy security. All of the transportation activities at ORNL—from lightweight materials to intelligent vehicles—address this human behavior by coming up with technologies to deal with those consequences."

Will telecommuting—working at home and communicating with the office by computer—cut down on traffic congestion? David Greene, Ed Hillsman, and Amy Wolfe in ORNL's Energy Division developed a computer model to study this question. **(continued on p. 82)**

As a result of the national traffic jam, ... more carbon dioxide and pollutants are needlessly discharged to the air.

David Greene: Painting the Big Picture

David Greene, a senior researcher with ORNL's Center for Transportation Analysis, has studied fuel economy in vehicles for nearly 20 years. He has a firm grasp of the myriad statistics and cause-and-effect relationships involved in getting people and products from place to place. Mention, for instance, that the fuel economy of the freight carriers has improved, and he responds that it isn't necessarily true; perhaps on a vehicle-mile basis, but not on a ton-mile basis, where it really counts. The causes, he says, range from a shift from rail and water to motor carriers to just-in-time manufacturing, which makes timely delivery more important than carrying a full load. With that sort of depth perception, he is a widely recognized and often-cited expert in his field.

Fuel economy is about twice what it was in 1974.

On efforts to meet the challenges posed by a burgeoning need for transportation coupled with concerns over energy supplies and environmental effects, Greene says that inventing better machines, not changing consumer behavior, has been the preferred strategy. "Because there is no concerted effort to raise fuel economy standards, subsidize alternative fuels, or raise the gasoline tax," he notes, "we have basically put all of our eggs in the long-run technological improvement basket through the Partnership for a New Generation of Vehicles.

"Gradual improvements in technology can work—fuel economy is about twice what it was in 1974, rising from 14 to 26 miles per gallon for vehicles of comparable size, weight, and horsepower. This is largely a result of technological efficiencies introduced in the areas of fuel injection, electronic engine controls, combustion technologies, vehicle weight, aerodynamics, tires, and transmissions."

Greene has studied the implications of replacing internal combustion vehicles with electric cars and gasoline with alternative fuels such as ethanol. He notes that for the next few decades electric vehicles will contribute little to reducing carbon dioxide emissions because their batteries must be frequently recharged. The sources of electricity for recharging are mostly carbon-based fossil fuels.

Are there gasoline substitutes for vehicles that emit lower levels of carbon dioxide and other greenhouse gases? Says Greene: "We currently have the technology to easily use several alternative fuels, including ethanol, methanol, natural gas, and propane. Unfortunately, right now these fuels don't buy us much in terms of decreased greenhouse gas emissions. There are cleaner fuels around, but in each case, either the

As a researcher in ORNL's Energy Division, David Greene's world revolves around the plethora of vehicles in the world and the ramifications of policies designed to deal with them.

fuels or the means of using them are not widely available. At the same time, gasoline has been 'reformulated' to make it cleaner, outcompeting alternative fuels in terms of cost-effectiveness.

"There are only a few fuels that we have the technology to deal with that give improvements in greenhouse gas emissions. And producing so-called clean fuels often yields little or no net benefit. For example, when ethanol is produced from grain, the result is a fairly clean-burning fuel. But current farming methods require a great deal of fossil fuel to be burned to produce and transport the grain and fertilizers and distill the alcohol in the first place. So the advantages of the end product are cancelled out by the fuel consumption necessary to provide the raw material. The same is true of efforts to produce cleaner energy sources from fossil fuels, such as deriving methanol or electricity from coal.

"Ideally, clean fuels would be derived from relatively clean sources, such as electricity generated using hydropower or hydrogen produced from water using solar photovoltaic panels. Another option would be to develop ways of producing renewable fuels, such as biomass, that require less fossil energy. Methanol's performance is as good as gasoline, but if we make it from natural gas, it doesn't do us any good from a greenhouse gas perspective.

"If we had widely available biomass fuels—like alcohols—that were produced using a minimum of fossil fuel, we could produce a 'flex-fuel' vehicle that could run on any mixture of ethanol, methanol, or gasoline, as long as the mixture contained at least 15% gasoline. These vehicles already exist; estimates of the added cost of mass producing them range from $100 to $300. This is a classic chicken and egg problem—either we don't have demand for the vehicles because we don't have the fuels, or the other way around.

So how do we get there? "In the short term," Greene says, "the government is trying to require vehicle fleets to use some of the alternative fuels—even if they don't provide much of an advantage in the production of greenhouse gases. In the long term, the government, industry, and the national labs are teaming up in the Partnership for a New Generation of Vehicles. The partnership is gradually settling on a hybrid design, hoping that a hybrid configuration will produce the best combination of performance, energy efficiency, and environmental friendliness."

Greene notes that greenhouse gas emissions are linked to the use and fuel economy of vehicles. He provides a historical perspective.

"From 1974 through 1982, in response to the Arab oil embargos, to oil price shocks, and especially to federal fuel-economy standards, the efficiency of new cars introduced to the U.S. fleet doubled. The fuel economy of new cars introduced after 1982 has not improved significantly, but the U.S. fleet's average miles per gallon continued to increase as the older cars were replaced with the newer, more-efficient ones. Even during the 1980s, greenhouse gas emissions from highway transportation increased as the growth of vehicle travel outpaced efficiency gains. By 1992, however, the new car MPG improvements had worked their way through the fleet of new and used vehicles. In 1993 and 1994 the on-road fuel efficiency of the fleet declined slightly. Urban driving and traffic congestion continue to rise, further increasing greenhouse gas emissions.

"Greenhouse gas emissions also may rise slightly as a result of the repeal of the national speed limit on interstate highways, which is likely to encourage faster driving. About 23% of U.S. automotive travel is on interstate highways, the main routes potentially affected. Although we don't have good information on the actual speeds that people have driven in the past and don't yet know what speed limits the states will impose, we are sure the repeal will hurt fuel economy and increase greenhouse gas emissions. A good guess is that fuel consumption and greenhouse gas emissions will each rise by about 1%."

—Bill Cabage

Greenhouse gas emissions also may rise slightly as a result of the repeal of the national speed limit.

"We found that telecommuters will drive fewer vehicle miles, reducing fuel consumption and reducing congestion," Greene says. "Remaining traffic would move more efficiently, further cutting fuel consumption. However, reduced congestion might induce drivers who normally avoid heavy traffic to use highways more during the day, increasing fuel consumption. Because telecommuting allows people to live and work farther apart, increased urban sprawl could result, increasing driving distances and fuel consumption. On balance, telecommuting appears to provide significant reductions in fuel consumption, thus decreasing emissions of carbon dioxide."

Telecommunications technology, particularly the broadband information highway, could further reduce fuel consumption, Greene says. "People will drive less if they rely on the information highway to do their shopping and banking, to pay their bills, to send their letters, and to provide education and medical advice."

Smart Vehicles and Highways

Tight budgets and land-use restrictions mean that we can't just keep building more highways to accommodate the growing number of cars. Is there a technological fix to move traffic more efficiently and safely? Is there a solution to the traffic congestion problem?

State and local governments, national laboratories, universities, the transportation industries, and companies that were defense contractors during the Cold War have teamed to work on constructing the Intelligent Transportation System (ITS) under the leadership of the U.S. Department of Transportation. Smart cars and smart highways are now technologically feasible because of recent advances in computing, communication, display, and sensing technologies.

"One of ORNL's greatest successes has been our work with the ITS," Honea says. "Our involvement has grown from a few hundred thousand dollars worth of research to nearly $20 million in 1995. This is an area of research that isn't going away. It is estimated that, in the long term, the technology that will make for safer, more-efficient highways will be a $300 billion-dollar investment, most of which will be shouldered by the private sector.

"In addition to making our highways safer," Honea says, "ORNL is a partner in improving the safety of the cars we drive. We are doing research in car crash avoidance that will contribute to the design of crash avoidance systems."

When ORNL researchers first got involved with the ITS program, the only thing they had to worry about was the simulation of traffic flow on highway networks. Today the ITS program looks at virtually all aspects of applying advanced technology to transportation systems, including safety, navigation, congestion, and environmental impacts. "We have broadened our horizons somewhat," program director Ajay Rathi notes wryly.

Building on their experience with modeling traffic flow, ORNL researchers' ITS traffic research is spread over 20 different projects. Their studies range from mathematically modeling an ITS system to developing the electronics and other technologies that will make intelligent vehicles and highways a reality.

"Probably our most important project right now is the Real-Time Dynamic Traffic Assignment Model," Rathi says. "Eventually, the system will consist of a network of traffic sensors around a metropolitan area, for example, that communicates with a central traffic computer. Electronic information from on-the-road sensors will be supplemented with information on what traffic is usually like this time of day and instantaneous updates from drivers calling in on cellular phones. Vehicles will be equipped with an on-board navigator that will garner up-to-the minute traffic information from the central system on alternative routes, the time a certain route is likely to take, and 'forecasts' of expected traffic conditions. This effort will involve hundreds of miles of roads and thousands of vehicles. It may well stretch the limits of computing and mathematical modeling." Over the next 5 years, ORNL's job is to demonstrate the model under real-world

operational conditions in Atlanta and beyond to provide real-time route guidance to drivers.

Another project of Rathi's group is working with the Federal Emergency Management Agency to develop software to model emergency evacuations. This simulation is designed to help planners cope with the overwhelming number of variables that come into play during an evacuation.

"Ideally, people either leave town in their cars or stay where they are and put on protective equipment," says Rathi. "But things aren't usually that simple. Variables such as reaction time, number of people being evacuated, the types of vehicles they're driving, the area of the evacuation, destinations of the evacuated, human behavior, traffic flow, and other parameters are being considered in the simulation."

The Cognitive Systems and Human Factors Group of the Intelligent Systems Section within ORNL's Computer Science and Mathematics Division is developing an Advanced Traveler Information System. The group, led by Bill Knee, takes a broader view of transportation safety. Using technology originally developed by the U.S. military for helicopter navigation, the system alerts drivers to potential traffic hazards and slowdowns on the way to their destination and suggests the quickest ways around them.

This high-tech road map is scheduled to be up and running in time for the 1996 Summer Olympic Games in Atlanta. Part of the system will be set up in traveler information displays at Atlanta's airport, hotels, malls, and Olympic village. These displays will supply travelers with a schedule of Olympics events of the day and recommendations on the quickest route to these events and the best places to park.

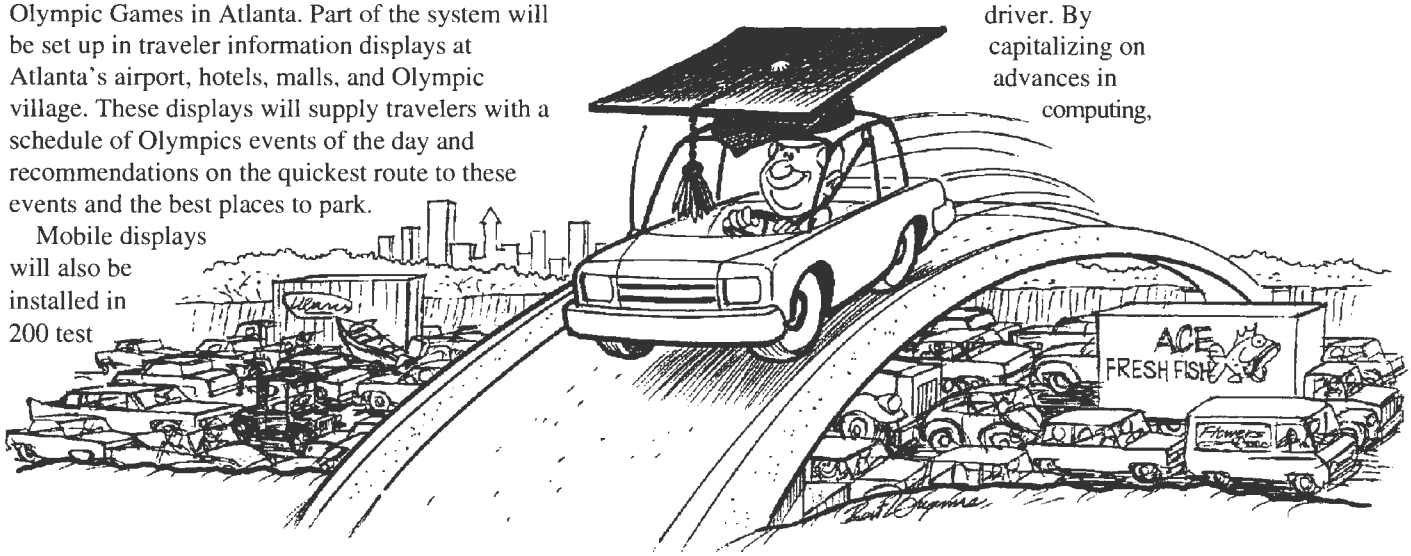
Mobile displays will also be installed in 200 test vehicles and will offer five levels of information, ranging from simple warnings, such as "construction ahead," to an electronic road map showing the location of the vehicle, areas of traffic congestion en route to its destination, and suggested alternative routes. "The navigation display can really be valuable to the driver," says Richard Carter, a staff psychologist in the group. "It gives you an up-to-date, blow-by-blow description of what's going on down the road, so you don't end up stuck in traffic."

Carter has high hopes for the system. "We are using the most sophisticated technology available to reduce traffic congestion and move people to their destinations," he says. "All of the displays will communicate with a traffic control center, which will process a constant stream of data from road-based traffic sensors around Atlanta and from the Global Positioning System satellite overhead." The result will be unprecedented: an up-to-the-minute traffic advisory, custom-tailored to the traveler's location and destination.

"It's the least we can do," says Carter. "The world is coming to visit."

Recently, the Cognitive Systems and Human Factors Group arrived at functional requirements for an In-Vehicle Signing system to be developed for the Federal Highway Administration. An In-Vehicle Signing system will bring information from roadway signs, signals, and pavement markings into the vehicle and present it to the driver. By capitalizing on advances in computing,

The system alerts drivers to potential traffic hazards and slowdowns and suggests the quickest ways around them.



communications, and display technologies and by applying principles of human factors psychology, In-Vehicle Signing will be designed to tailor the display of sign messages to the individual driver and to the current driving situation.

The In-Vehicle Signing system has three functions important to the driver. One is an information filter to ensure that only messages important to the driver are displayed (such as directions for a particular route number). The second is a display that takes into consideration lighting, driver preferences, and other simultaneous messages; it also monitors whether a driver is responding to messages (stop signs, for instance) and adjusts the display accordingly. The third is the timing function, which determines the onset of a sign display to give the driver and vehicle enough time and distance to respond; it displays relevant sign messages for the entire time that they apply (such as speed limits) and for only the time that they apply (such as a traffic light).

Work on an In-Vehicle Signing prototype is scheduled to begin in 1996. Eventually, this system will play a major role in controlling the vehicle, whether it is being driven by a human driver or piloted by an automated highway system.

Steve Allison, David Howell, and Gary Capps, all of ORNL's Engineering Technology Division, are working with Supercond Technology, Inc., in Atlanta to develop a traffic monitoring system, again for the Summer Olympic Games in 1996. The goal of this CRADA is to improve the traffic flow during the games in Atlanta, which is noted for its traffic even in normal times. ORNL researchers will conduct tests to guide the development of smart structures made of sensors embedded in road materials. The sensors must be able to endure extreme temperatures and other harsh road conditions and be compatible with asphalt and concrete. Staff at computer control centers will use smart structures incorporated in major highways to monitor the pace of traffic and identify slowdowns.

Crash Avoidance

When traffic gets heavy, the chances that autos will collide increase. Carter and his colleagues are working to reduce those chances. They are collaborating with Scientific Atlanta and others to study driver behavior with the goal of developing technology to head off collisions with nearby vehicles.

They are studying driver behavior with the goal of developing technology to head off collisions with nearby vehicles.

Carter'steam, assisted by Scientific Atlanta and other partners, is developing an outfitted car called DASCAR (data acquisition system for crash avoidance research) for acquiring information on driver behavior and responses during accidents and near misses. The work is being performed for the National Highway Traffic Safety Administration (NHTSA). This advanced data acquisition system provides an up-close-and-personal look at drivers' responses to traffic problems courtesy of a fleet of test vehicles outfitted with high-speed computers, video cameras, and motion sensors. All of this gadgetry gives each vehicle's on-board computer a precise picture of the traffic around it, and a satellite hookup enables the vehicle to know exactly where it is by tapping into information from the Global Positioning System satellites. This tracking system is so accurate that it can determine the vehicle's position along the road and even within its own lane. Computers also take note of other driving-related factors, such as the driver's heart rate and brain functions, as well as braking, steering, and whether the radio and wipers are on or off.

This wealth of data will enable researchers to determine exactly what happens before and during accidents or near misses. "These specially equipped vehicles," says Carter, the principal investigator, "will be used both on a test track and on the open road to test the effects on driver performance of various conditions ranging from the weather to traffic congestion."

DASCAR, which is noted for being the first CRADA associated with the ITS program, has been successfully demonstrated to NHTSA and other DOT officials. It was so well received that it was also paraded before members of Congress and the national press corps. This year a fleet of 15 vehicles is scheduled to make its debut—first on the track and then on the road. Carter hopes these tests will shed some much-needed light on the 1-second window before a crash or a near

miss. "Most vehicle crashes," he says, "could be prevented if the correct action is taken within a half second to a second before the collision."

Using the data provided by the smart car project, Carter envisions the development of an intelligent cruise control that could react to changes in the speed and distance of other vehicles—keeping both driver and car out of harm's way. "The ITS project lays the groundwork for a truly intelligent vehicle," he says. "If we can use this system to determine what information a driver needs to escape collisions, the next step will be to develop a computer-controlled vehicle that can take control of its own movement when an accident is imminent and avoid it."

Transportation Data

Transportation researchers, according to Mike Bronzini, director of ORNL's Center for Transportation Analysis, are also taking advantage of state-of-the-art computer-based mapping techniques to develop geographic information system (GIS) databases for the nation's transportation systems. These include road, rail, water, air, pipeline, and "intermodal" systems—those that employ several modes of transportation. GIS and other data indicate the locations of roads, the type of road (interstate or secondary), the road's capacity, the typical volume of traffic on the road, and types of traffic signals or other controls that are present. These data enable companies such as freight carriers to route their vehicles more efficiently and track shipments. GIS information also provides a basis from which federal, state, and local governments can plan improvements in their transportation infrastructure. For ITS development, GIS data are useful for the creation of maps for on-board navigation systems in vehicles.

"Ultimately," says Bronzini, "having the data made available by the government ought to reduce industry's cost for this kind of information. Customers will eventually take

Considering all of the electronic equipment that intelligent vehicles will require, will there be any trunk space left? Thanks to the microchip and miniature technology, ORNL researchers can conceal electronics in the rear-view mirror.

Frank Barickman uses a voltmeter to check a laser device on a vehicle outfitted to collect data on the behavior of drivers in various situations. The information could aid the development of crash-avoidance technologies.

Richard Carter programs a test vehicle with a laptop computer. ORNL researchers are working with Scientific Atlanta to equip automobiles with data acquisition systems to obtain information on driver behavior.

the data we're providing and modify them to suit their requirements."

Complete and accurate data on the nation's transportation resources are essential for developing policy and increasing the efficiency of industy and commerce through improved traffic flow. Over the past few years, Bronzini says, ORNL researchers have been assessing the quality and coverage of transportation data and have begun the task of filling in the gaps.

One longstanding gap was found in information on the flow of goods, or commodities. So ORNL is helping the U.S. Department of Transportation fill the void with the agency's national commodity flow survey. Targeting 200,000 establishments that ship out goods 12.5 million times a year, the survey asks, "What are you shipping?", "How are you shipping it?", "How much are you shipping?", and "Where are you shipping it to?" The initial results from this survey were published in July 1995. Proper use of this information should lead to improved efficiency in traffic and commodity flow.

Another gap is being filled by the Department of Transportation's American Travel Survey, in which ORNL is participating. This computer-aided telephone survey targets trips of 100 miles or more. It tracks travelers' modes of transportation, the distance traveled on each leg of the trip, and the total length of the trip.

"Similarly," Bronzini says, "we are also helping to lay the groundwork for a new National Highway System by combining the resources of disparate databases, such as GIS databases and the National Highway Planning Network. Our task is to determine the highways that serve a national purpose. We are working with the Federal Highway Administration to build a massive database, covering some 400,000 miles of U.S. roads. This kind of information has a number of applications, including helping policymakers determine where to spend scarce dollars to improve or maintain the nation's heaviest-used highways."

It is hoped that use of these data systems will result in improved efficiency in construction and operation of highways to reduce traffic congestion, energy consumption, and greenhouse gas emissions.

Fork in the Road

The transportation revolution has helped the world's economies prosper and grow. But down the road it could threaten the economies it helped simply through the excesses brought on by its success. Greenhouse gas emissions are increasing partly as a result of the growing use of vehicles and more traffic congestion; the resulting climate changes that many people expect could be

disastrous to affected economies. The gasoline that fuels most cars in the United States comes from imported oil. Its price is almost sure to rise, and some say we could run out of oil altogether, possibly during our lifetime. In addition, traffic congestion causes more accidents, reduces the efficiency of the economy, and emits pollution that harms human health.

Fortunately, a revolution in computing, communication, display, and sensing technologies can make mid-course corrections in the transportation revolution. It is now possible to put a new spin on the transportation wheel. Through development of clean, efficient cars and smart vehicles and highways, the transportation revolution that threatens to derail economies can get them back on track. ORNL is contributing to the development and testing of these technologies. As long as there is a demand for better transportation technologies, ORNL's transportation research should continue to roll.**ornl**

The Center for Cooperative Transportation Research

In light of the Southeast's growing importance as a center for automobile and truck manufacturing—Saturn, BMW, Mercedes-Benz, Ford, GM, Nissan, and several heavy-duty truck and bus manufacturers all have factories in the southeastern states—it's not too surprising that a transportation technology research center has been proposed for the region. ORNL and the Oak Ridge Y-12 Plant are partners in a group proposing to build the center, which would be located between Oak Ridge and Knoxville.

The Center for Cooperative Transportation Research will house millions of dollars worth of state-of-the-art equipment for transportation-related research such as dynamometers, flywheel test labs, and structures testing equipment. It would provide laboratories to test new transportation concepts and technologies to benefit the Southeast's growing transportation industry as well as to serve the needs of government agencies such as the U.S. Department of Energy, the U.S. Environmental Protection Agency, and the military.

The center is a cooperative effort among Lockheed Martin research facilities in Oak Ridge, the University of Tennessee at Knoxville, and the Development Corporation of Knox County. It is proposed for a site on the Pellissippi Parkway, a thoroughfare between the cities of Oak Ridge and Knoxville with adjoining land that has been set aside for high-tech industries. The site would be equally convenient to the Oak Ridge complex, the university, and the Knoxville airport.

Bob Honea, director of the Oak Ridge Transportation Technology Center, says, "The facility will resemble ORNL's High-Temperature Materials Laboratory in that it would pull together experts from industry, academia, and government research facilities to tackle transportation problems. There are already millions of dollars of transportation research being conducted between the university and Oak Ridge. This new center would serve as a catalyst both to showcase the existing capabilities as well as to develop new capabilities and talents.

"Right now, there isn't a jointly operated research center devoted to transportation like this anywhere in the country. This kind of facility will help accelerate advances in transportation research as it serves the regional interests of the Southeast. We expect that in addition to serving the researchers' needs for new facilities, it will also serve the needs of the local industry by providing a new user center with unique facilities."

Supporters of the center hope it will attract not only guest researchers, but also interested companies to the area. Tennessee already leads the Southeast in bringing in new assembly plants: a Nissan plant in Smyrna, a Saturn plant in Spring Hill, and a Peterbilt truck facility in Madison. According to the Federal Reserve, Tennessee is the only state in the Southeast that surpasses the national average of 4.1% automobile manufacturing employment. With its figure of 6%, Tennessee ranks behind only Michigan and Ohio nationally in automobile manufacturing employment.

In addition to the center, more industrial interest in the region should be stimulated by the presence of several automobile manufacturers and suppliers, the Oak Ridge Centers for Manufacturing Technology (which is developing processes for efficiently manufacturing cars), and ORNL's High Temperature Materials Laboratory (which is helping to develop materials for efficient engines). One of every seven manufacturing jobs in the United States is related to the automobile industry: Oak Ridge's new focus on transportation technology could help draw more manufacturing jobs to the region.

Saving Energy in Buildings and Appliances

By Carolyn Krause

In the past, buildings and appliances have been constructed to last. Now, they also must be made more efficient to save energy and money. Energy efficiency also has important environmental benefits. Use of less fuel reduces emissions of pollutants that threaten the health of people, animals, plants, and ecosystems. Also, it can delay potentially undesirable changes to the global climate that might occur if atmospheric carbon dioxide emissions from fossil-fuel combustion increase enough to raise the earth's surface temperature significantly. ■ About 50 Oak Ridge National Laboratory researchers and numerous industrial researchers have been working together on improving U.S. building energy efficiency at the Buildings Technology

This aerial view of ORNL shows the Buildings Technology Center—the three buildings with white roofs approximately in the center of the photograph.

The BTC provides the building and appliance industries with broad access to a unique collection of testing and analysis capabilities.

Center (BTC), national user facility in ORNL's Energy Division that is supported by DOE's Office of Building Technologies.

The BTC provides the building and appliance industries with broad access to a unique collection of testing and analysis capabilities. The special focus of these capabilities is energy-efficiency improvements.

In ORNL's Building Envelope Research Center, Phil Childs works with Clayton Homes and Phase Change Technology to develop future insulation panels for mobile homes and other manufactured housing. Here, full-size roof sections are tested. At center, attic insulation and conditioned air ducts are tested to guide industry in building better, more energy-efficient attics. In ORNL's Rotatable Guarded Hot Box at right, Laboratory and industrial researchers work together to test full-size walls to determine their energy performance. *Photograph by Tom Cerniglio.*

BTC is devoted to building envelope research, development of heating and cooling technology, and existing buildings research. Here are some of its achievements.

In building envelope research, BTC participants determined the thermal performance of different types of roof, attic, wall, and foundation insulations, including alternative insulations that do not contain chlorofluorocarbons (CFCs), which threaten the earth's protective ozone layer. They developed decision guides and databases for roof, wall, and foundation construction; with this information, for example, a building designer can determine if the selected roof

color and slope are cost effective. They found the cause of significant heat losses from low-density loose-fill insulation in attics in cold climates and identified insulation strategies that reduce these losses. As a result, improved attic insulations have been installed in affected homes in northern states.

In heating and cooling technology, BTC researchers evaluate high-efficiency electric and gas heat pumps in the laboratory and field. They assess options for improving energy efficiency of central heating plants and cogeneration plants that provide both heat and electricity. They design and test modifications to refrigerator-freezers that improve their energy efficiency and eliminate CFC refrigerants. They assess the global-warming impact of CFC alternatives.

In existing buildings studies, the researchers develop and field-test energy diagnostic procedures for residential and commercial buildings. They have discovered ways in which to improve dramatically the energy evaluation and performance of the building structure, its heating and cooling equipment, and its thermal distribution system. As a result, they have provided important advanced technologies for major initiatives like the Weatherization Assistance Program, the Affordable Homes Partnership of the departments of Energy and Housing and Urban Development, Rebuild America, and Energy Efficiency in Military Family Housing.

The following articles are devoted to special BTC topics: refurbishment of old roofs, energy audit software, energy losses from ducts in homes, energy use in commercial buildings, and refrigeration and heat pump research. **ornl**

As a result of BTC work, improved attic insulations have been installed in homes in northern states.

A New Look at Old Roofs: *Replace or Recover?*

Phil Childs checks the moisture content in roof insulation for Building 2518.

As homes and commercial buildings age, their roofs often begin to leak. When a roof is 15 to 20 years old, a typical building owner will have it replaced. But, is a costly replacement of a roof needed so soon? Not always, say researchers at ORNL's Buildings Technology Center.

The researchers are finding ways to dry a wet roof and extend its life by five years at one-third the cost of replacing it. They also are identifying methods of building new low-sloped roofs that dry easily and can be re-covered to make them last longer. These techniques, they say, will save energy and money.

BTC researchers David Kyle and Andre Desjarlais have written an *Assessment of Technologies for Constructing Self-Drying Low-Slope Roofs*, which evaluates currently available techniques for removing water from flat roofs. According to Tom Smith, director of the National Roofing Contractors' Association, this report has been cited by roofing contractors as "one of the most important reports . . . to come out in the last five years."

Traditionally, after 15 years of use, an old roof assembly is torn from the metal deck and replaced at a cost of about $9.00 per square foot. Adding to the expense is the cost of landfill disposal of the large volume of old roof parts, including asphalt, foam, and asbestos, which are no longer classified as a single construction waste.

To reduce the cost of roof repair to one-third that of the traditional tear-off approach, more and more building owners are asking roofers to dry out their roof insulation and cover it with a new top layer. BTC researchers say this approach offers benefits to consumers and the country.

"An increase in roof service life of 5 years in the United States should reduce the cost of roofing by 21%, saving the country $2.5 billion a year and cutting by 25% the landfill waste from roofing, which currently represents almost 4% of the total volume of solid wastes in the United States," says Jeff Christian, manager of ORNL's Buildings Envelope Research Center. "This savings is possible if roofers could dry out and re-cover old roofs and build new self-drying roofs that can be safely re-covered later."

Starting from the bottom up, a typical roof comprises a corrugated metal deck, two layers of foam insulation, and a membrane made of sheet rubber or plies of felts mopped together with asphalt. Water eventually enters gaps in the roof assembly, leading to its deterioration. As the moisture accumulates, metal fasteners may corrode, the ability of roof insulation to keep out heat may decrease by as much as 40%, and dripping water may enter building interiors, causing damage and motivating owners to consider roof repair.

How can an old roof be dried most rapidly before covering it with a new membrane? ORNL researchers and their industry partners at the Buildings Technology Center have identified effective ways to reduce and prevent moisture accumulation in roofs.

"We are studying moisture and heat flow in low-slope roofs to learn how to make them last longer," Christian says. "To determine the best alternative solutions for roof repair, we have combined field diagnostics, laboratory experiments, computer modeling, and assessments of available techniques for drying out roofs."

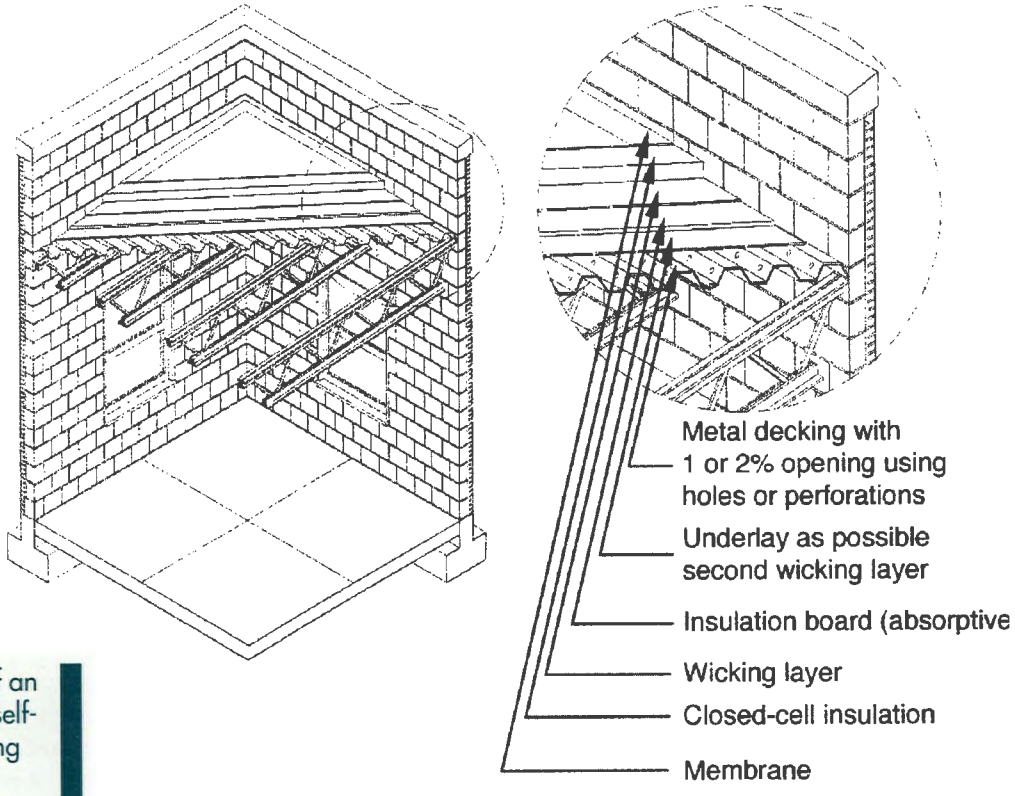
Researchers have found some special materials, called vapor retarders, that block the flow of water into a roof assembly. Other materials absorb water as liquid and release it downward as vapor. When this vapor reaches the building interior, it can be removed by air conditioning.

BTC researchers Christian, Desjarlais, and Phil Childs in collaboration with Dow Corning researchers are demonstrating "downward drying" in Building 2518, which is home to ORNL's Plant and Equipment Division. Using infrared cameras and neutron sources, they found that 40% of the insulation in the 27-year-old roof was saturated with water.

They repaired the leaks and increased the roof's insulating ability from R-2 to R-13 by spraying the roof with polyurethane foam. Before reroofing, holes were drilled in the metal deck and vapor retarder to let vapor from the insulation pass through the roof deck below. In this way, the wet insulation dried out.

In the summer the large difference in the pressure of vapor in the roof and in the air-

Researchers are finding ways to dry a wet roof and extend its life by five years at one-third the cost of replacing it.



Schematic of an engineered self-drying roofing system envisioned for the future.

The BTC effort saved ORNL $250,000 in roof replacement and disposal costs.

conditioned space inside forces the vapor down into the building, where it is removed by air conditioning. The roof's outer membrane was covered with white granules (donated by 3M Corporation) that reflect sunlight more effectively than typical black roofs, reducing the air-conditioning load on the building.

The researchers removed wet roof samples from Building 2518 and thermally tested them in the Large-Scale Climate Simulator while weighing them on "load cells." The Large-Scale Climate Simulator was programmed to reproduce summer outdoor weather conditions. They measured loss of moisture mass over time, confirming downward drying.

They also conducted neutron gauge surveys of the moisture content in the Building 2518 roof to measure vapor losses. They sent sample materials to the National Institute of Standards and Technology to measure their vapor permeability and capillarity. Based on periodic data obtained, they modeled the roof system on the computer so they could predict how fast the roof will dry out.

By not replacing the roof at Building 2518 by the typical procurement process and by having Dow Corning re-cover the roof as part of its contribution under a cooperative research and development agreement, the Buildings Technology Center effort saved ORNL $250,000 in roof replacement and disposal costs. Based on computer modeling of energy use before and after the roof work, the researchers found that the installed insulation and reflective granule reduced heating costs by 42.5% and cooling costs by

18.5%, saving the Laboratory $2300 a year in energy costs.

"From our experiences with Building 2518, we learned that roofs that have vapor retarders will not dry out easily," Christian says. "For the engineered self-drying roofing system of the future, we recommend installing a vapor retarder only if it is water-permeable and a perforated deck so that water vapor will pass into the interior for removal by air conditioning. We also recommend an easily removable membrane as well as permeable insulation and a wicking layer that absorbs liquid water and passes it into the building as a vapor.

"Lessons learned from this work are being incorporated into a software program that will help roofing contractors decide whether re-covering individual old roofs is a viable alternative. The software may also guide the design of future roofing systems."

Christian says that the Building Envelope Research Center is negotiating users' agreements with roofing companies on designing engineered self-drying roofs for new buildings. "We think our knowledge can be applied to new construction, as well as roof retrofits," he says. "Our research results and experience suggest that re-covering self-drying roofs and old wet roofs that are dryable should extend roof life, reduce landfill waste, improve building energy efficiency, and save consumers money."

A goal is to design engineered self-drying roofs for new buildings.

New Type of Steel Stud Tested at ORNL

Because steel is becoming cheaper than wood, is recyclable, and is resistant to mold and termites, steel studs are increasingly being selected by builders over wood studs for home construction.

Recently, a Buildings Technology Center user, aided by an ORNL researcher, tested a new type of steel wall stud that will enable future new homes to hold in—or keep out—more heat. The tests showed that the new studs would make walls 10 to 15% more energy efficient than wall systems containing conventional steel studs. The results suggest that widespread use of new steel studs in new home construction, when compared with conventional studs, will reduce the consumption of fossil fuel to heat or cool new homes and lower carbon dioxide emissions.

LeRoy Landers, a professor of architecture at the University of Pennsylvania and a candidate for a doctorate in architecture design, conducted a series of tests at ORNL using BTC equipment. He conducted his research with the help of Andre Desjarlais of ORNL's Energy Division.

Thermal performance is improved because of the metal stud's reduced surface contact with the inside and outside wall sheathing. The experimental steel stud was tested in a wall with fiberglass batt insulation filling the cavity which is sandwiched between plywood and gypsum board sheathing. The wall was exposed to a temperature difference across the wall of 50°F in BTC's Rotatable Guarded Hot Box.

One use for measurements on new wall systems such as Landers' is to help develop a way to evaluate the thermal performance of a total wall system, not just its insulation. Jeff Christian, manager of BTC's Buildings Envelope Resesarch Center, says, "We must consider the whole wall system, including structural parts such as studs and materials used to hold walls to other walls, doors, windows, roofs, and floors. Our goal is to offer the building industry a method of developing a new consumer label that represents the whole wall and not just the misleading 'center-of-cavity' R-value rating on insulation."

NEAT Success Story: ORNL Software Saves Energy

In 1995 NEAT was used in 30 states to make retrofitting decisions for more than 80,000 low-income, single-family dwellings.

A woman from the local community action agency visits an elderly widower's home, bringing a laptop computer and printer. She and her partner inspect parts of the house, check it for air leaks, and ask the homeowner questions. She enters some data into the computer on the house's walls, doors, attic, insulation, and heating and cooling systems. Then she prints out a list of recommendations and hands the printout to the homeowner.

"You will save money and be more comfortable," she says, "if you add insulation to your attic, replace your old furnace with a high-efficiency furnace, and install a 'smart' thermostat. In a few days, a team will come by to install these recommended measures at no cost to you."

Homeowners throughout the United States are making home improvements that help them save energy, thanks to a computer program developed by Mike Gettings, Terry Sharp, and others in the Existing Buildings Research Group at ORNL's Buildings Technology Center. The user-friendly computer program determines the most cost-effective retrofit measures that will increase a home's energy efficiency and comfort levels.

National Energy Audit (NEAT) software was developed at ORNL for DOE's Weatherization Assistance Program, which provides funds for installing energy-efficiency measures in the homes of low-income families with children, the elderly, and people with disabilities. In 1995 NEAT is being used by about 500 local agencies in 30 states to make retrofitting decisions for more than 80,000 low-income, single-family dwellings. Several electric and gas utilities have adopted it for demand-side management programs to reduce consumption of and peak demands for electricity and natural gas.

"Field tests show that use of low-income house retrofits identified by the NEAT program reduced energy use for space heating by at least 25% whereas standard retrofits cut energy use by only 18%," says Ron Shelton, manager of the Existing Buildings Research Group. "Use of NEAT rather than standard approaches in these 80,000 homes is projected to save $70 million over the lifetime of the retrofits performed this year."

Energy savings for utilities by installing NEAT's recommended measures in 80,000 homes could total $70 million.

The current program is menu-driven. However, an optional version using a mouse is under development for users who like to point and click on screen buttons and bars.

Since 1976, DOE's Weatherization Assistance Program has reduced heating and cooling costs for low-income families by identifying ways to increase home energy efficiency and providing funds to install the measures. Efficiency measures were normally selected from a standard list of building envelope measures, such as adding insulation and storm windows and sealing cracks and crevices through weatherstripping and caulking.

In 1985, DOE's Existing Buildings Efficiency Research Program began conducting field tests in Wisconsin and New York of comprehensive audit approaches such as NEAT. These field tests, together with a third field test cosponsored by the Weatherization Assistance Program in North Carolina, showed the value of NEAT. Its strategies resulted in greater energy savings for every dollar invested because it selected the most cost-effective options.

Mike Gettings (right), principal developer of the National Energy Audit (NEAT) software for analysis of home energy use, calls attention to a feature on one of the computer program's input screens. At the keyboard is Regina Parks, a program secretary at ORNL's Buildings Technology Center. Terry Sharp (in background) concentrated on the software's application by conducting the field trial of NEAT in North Carolina and assisting in training seminars.

NEAT was first introduced to audiences nationwide through eight presentations during fiscal year 1993. At a recent national workshop, training on the use of NEAT was provided to representatives of at least 43 states.

A user inputs data on the building and its heating and cooling systems into the NEAT program. It responds with a prioritized list of cost-effective, energy-efficiency measures. NEAT's selected options are designed to correct costly inefficiencies in both the building envelope and the heating and cooling system. It customizes measures for individual homes. For the recommended retrofits, it produces estimated heating and cooling energy savings and their dollar value, savings-to-investment ratios, and a list of materials needed. It also uses billing histories to determine savings opportunities and reconcile engineering estimates of energy consumption and savings.

"The cost to DOE for developing NEAT is approximately $2 million to date," Shelton says. "Not counting future retrofits, the economic benefits to the country are 35 times the cost. And the long-term benefit for all of us is that we will not use up our energy supplies as fast and we will reduce emissions of greenhouse gases that could alter the climate."

The economic benefits to the country are 35 times the cost.

Sealing Duct Leaks Saves Energy and Money

A technician permanently seals the joint between the rooftop-mounted air conditioner and the metal ducts after adjusting the air conditioner's position using materials such as mastic, roof cement, and caulking.

A field technician points out the deteriorated seal between the rooftop-mounted air conditioner and the metal supply-and-return air ducts. This seal was a common leakage site that was repaired in the Arizona field test.

Energy is being lost unnecessarily in homes through heating and air-conditioning duct leaks resulting from deterioration or improper installation. By correcting these problems, says a BTC researcher, homeowners can save energy and money, and electric utilities can avoid building costly new fossil-fueled power plants and thus reduce growth in emissions of carbon dioxide to the atmosphere.

According to Mark Ternes of ORNL's Energy Division, "Ducts that pass through unconditioned spaces—attics, garages, or crawl spaces—have a good chance of losing energy. Losses can be very high if the ducts are uninsulated. Even when the ducts are wrapped with insulation, leaks at joints and corners can be big energy losers."

Leaks in supply ducts lose heated or cooled (conditioned) air to the attic or crawl space or between floors before the air can be delivered inside the house, wasting energy.

"If the return ducts in the heating and air-conditioning system have holes," Ternes says, "they can draw in attic air as hot as 130°F or outside air as cold as 0°F. As a result, the system must work harder and use more energy to heat and cool the inside of the house to the desired temperature."

Energy is also lost because differences in air pressure result from leaks in supply-and-return ducts. Air escaping from leaks in supply ducts must be replaced with air from outside the house, which is often much warmer or cooler than the conditioned air. "Additional energy," Ternes says, "is needed to condition the replacement air."

Sealing duct leaks in homes, Ternes says, can save energy and money based on the preliminary results of an ORNL study performed in the past two summers at Phoenix, Arizona. BTC researchers

monitored 100 houses, located and sealed leaks in ducts in 80% of the houses, and measured the energy savings and utility demand reductions for the retrofitted homes.

"We reduced duct leakages by 30%," Ternes says. "We found that the houses with newly sealed ducts reduced their energy consumption by 16% for an annual savings of about $80 per home."

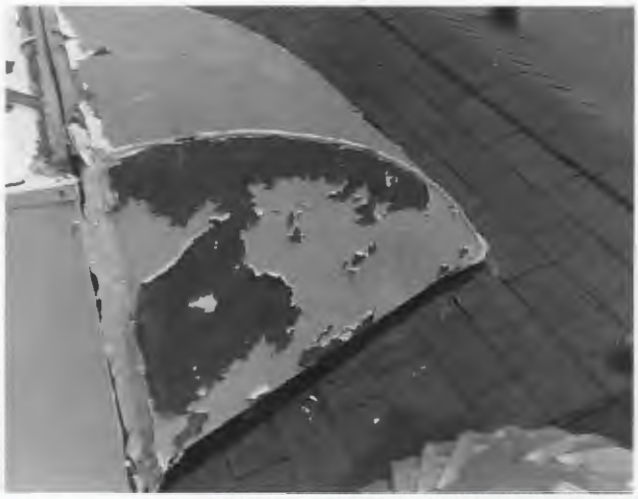
Because the cost per home for duct retrofits was about $200, Ternes says that homeowners would benefit from the savings within 3 years. "Utilities will benefit immediately from duct retrofits," he notes. "'In the Phoenix study, we found that the average peak demand for electricity fell 6%. Such a demand reduction could avoid the need for a new and costly power plant."

Results from this research will provide advice to heating, ventilation, and air-conditioning (HVAC) contractors; homeowners; and other involved parties on proper installation, placement, and retrofitting of ducts in homes to minimize energy losses.

"Some HVAC contractors seal duct joints with duct tape, which is often used improperly and which deteriorates in the hot air of attics," Ternes says. "We recommend connecting and sealing ducts with mechanical fasteners, mastic, and fiberglass tape, not duct tape." Mastic is a caulking material, and fiberglass tape provides rigid structural support when used with mastic.

"One problem that many HVAC contractors are not aware of," says Ternes, "is that the house often serves inappropriately as a duct. Many home HVAC systems are in interior closets or have return plenums built under stair wells. Use of closets and other parts of the house as a return duct can draw air from the attic or crawl space because of pressure differences. The solution is to use ductwork for all supply and return ducts, or seal the closet and house framing with mastic, sheet metal, or plywood if the house structure must be used."

Ternes says that Duke Power Company in North Carolina and electric utilities in California and Florida have programs for dealing with building duct losses. But, he adds, more work remains to understand the full benefits that can be achieved from duct retrofits and the best methods of achieving them.



The seal between the air conditioner and the metal supply-and-return ducts often fails on rooftop-mounted units because the sealant material deteriorates after long-term exposure to ambient temperatures and the sun. Also, the air conditioner pulls away from the ducts as it settles on its mounting supports.

We found that the houses with newly sealed ducts reduced their energy consumption by 16%, saving $80 a year.

Mounting a home's air conditioner on its roof is a common installation practice in Phoenix, Arizona. Field technicians participating in an Arizona field test have found such units to be a frequent source of duct leakage.

How the Commercial Sector Can Save Energy

ORNL researchers analyzed the United Unions office building (shown here) in Washington, D. C., before and after energy conservation measures were installed.

Office buildings, department stores, and other buildings in the commercial sector consume about one-third of our nation's electrical energy. Deploying energy conservation measures in many large commercial buildings could reduce this consumption significantly, according to several recent ORNL studies.

A large office building in Washington, D.C., was studied by Howard McLain, S. B. Leigh, and Mike MacDonald, all of the Existing Buildings Research Group in the Buildings Technology Center of ORNL's Energy Division. Using a computer program, they analyzed the all-electric United Unions building before and after energy conservation measures were installed. These measures included modification and replacement of light fixtures and improvements to the heating, ventilating, and air-conditioning (HVAC) system.

The researchers simulated the building's energy consumption using the DOE-2.1D computer program. The program was then used to estimate the energy and cost benefits of the individual

conservation measures for a typical meteorological year.

"After the conservation measures were installed," McLain says, "the United Unions building used 37% less energy per year than it did before. The savings in energy costs totaled $163,000 per year, or 35% of the original building energy cost. This savings would cover the cost of the installed measures in 4.3 years."

Half of the savings was the result of the light-fixture changes. The other half was from HVAC system improvements.

"The newly installed computerized energy management and control system, while convenient for building operators, did not contribute much to energy savings," McLain says, "because the operators were already doing a good job with manual controls."

At ORNL, a building energy conservation experiment was carried out at the Energy Division Office Building (Building 3147). "In this building," MacDonald says, "new fixtures have fewer ballasts and fewer but more efficient lamps than the old fixtures. This change reduced the total amount of light by about 50% based on the fact that the building had more lighting than DOE standards allow. The electricity used for lighting was reduced by 70%, and total electricity use for this all-electric building decreased by almost 30%. However, lighting quality appears about equal to previous conditions."

In another study, MacDonald found that Commonwealth Electric, an electric utility in Massachusetts, saved energy in a demand-side management (DSM) program by giving tenants and owners of commercial buildings financial incentives to install more-efficient lighting.

"Throughout their history, utility DSM programs have saved a total of only about 0.3% of the energy used by residential and commercial buildings in the United States," he says. "Utilities are more strongly motivated by the potential to cut peak demands for electricity to reduce the need for costly new power plants and the associated financial risk.

"To achieve substantial savings, the United States needs a program 10 times larger than the collection of current DSM programs. An infrastructure of partnerships is needed to make it easier and more attractive for owners of commercial buildings, especially the large ones, to alter and maintain their buildings to save energy. Such an infrastructure is now being developed through the Rebuild America initiative."

In October 1993, President Clinton's Climate Change Action Plan was initiated in response to the Earth Summit in June 1992 in Brazil, which drew representatives from more than 200 countries. The plan's first item of action is the "Rebuild America" initiative, because energy use in buildings accounts for about 36% of the carbon dioxide emissions produced in the United States. These emissions could contribute strongly to global warming.

Energy use in buildings accounts for about 36% of the carbon dioxide emissions produced in the U. S.

BTC's Existing Buildings Research Group was one of the original participants in formulating the Rebuild America initiative. Much of the input came from ORNL's Bill Mixon (now retired) and Mike MacDonald. ORNL is now developing a handbook for Rebuild America "partners," in collaboration with other national laboratories and private organizations.

"Rebuild America," MacDonald says, "will involve partnerships of state and local governments and others who will deal with engineering firms, financial companies, and commercial building owners. The partnerships will help get financing for installing energy conservation measures in commercial and multifamily buildings."

Six partners were selected by DOE for financial assistance in the first round of partner selection. These six partners have goals of retrofitting 200 million square feet of commercial and multifamily buildings to save over 0.5 billion kilowatt hours per year of electricity and over 0.01 quadrillion British thermal units per year of natural gas.

In short, Rebuild America will make institutional arrangements to deploy existing energy-efficiency technologies in commercial and multifamily buildings. These measures can save significant amounts of energy and money and help protect the environment.

Fridge of the Future: ORNL's Refrigeration R&D

By Carolyn Krause

ORNL has been heavily involved in the refrigerator redesign efforts of the past two decades.

Fears about warming the globe may change the way we chill our foods. Concern about global warming, as expressed in the President's Climate Change Action Plan of 1993, is the latest motivation for putting future American refrigerators and freezers on a strict energy diet. A current national goal is to design an environmentally sound refrigerator-freezer by 1998 that uses half as much energy as 1993 models.

■ Interest in designing a more energy-efficient refrigerator is not new. It first became a goal almost 20 years ago. In the 1970s, the United States was relying on increasingly unstable supplies of imported oil for fuel, and energy prices began to rise. Utilities balked at building additional power plants because of rising costs and investment risks. As a result, a premium was placed on developing energy-efficient appliances, culminating in the passage of the National Appliance Energy Conservation Act of 1987. ■ In the late 1980s, refrigerator design was again a target of engineers because of the need to change the refrigerant and insulation used. The reason: the Montreal Protocol called for the phasing out of substances containing chlorofluorocarbons (CFCs) by the year 2000 because they were thought to be destroying the earth's stratospheric ozone layer. Ozone shields humans from solar rays that can cause skin cancer and cataracts. Among the CFCs to be phased out are common refrigerants like R-12 and the refrigerator insulation blowing agent R-11. ■ Today, the ozone-friendly refrigerant R-134a has been designated to replace CFC-containing refrigerants in new refrigerators because of its lack of chlorine, the main chemical element causing ozone depletion. However,

Brooks Lunger, a guest user at ORNL's Buildings Technology Center from DuPont, checks instrumentation on test refrigerators.

BTC is now working on developing a highly energy-efficient refrigerator-freezer that uses an efficient and environmentally acceptable refrigerant and insulation.

it may become a target for future phaseout because it contributes to global warming, although much less so than CFCs. In that event, its likely replacement will be a hydrocarbon such as isobutane or propane. These natural refrigerants will have to be "engineered around" in a new refrigerator design because they are flammable. Thus, their widespread use may slow global warming but raise the risk of house fires.

Large Energy User

Home refrigerators are a significant user of world electricity; hundreds of millions are currently in use, and 58 million new units are manufactured worldwide each year. In the United States, refrigeration systems (including air conditioners and heat pumps) account for 41% of the energy consumed by residential and commercial buildings. The buildings sector requires about 36% of the energy used in the United States. If no improvements are made, energy use in the buildings sector is projected to climb 37%—from 29 quads (quadrillion British thermal units) today to 40 quads—by 2010.

The goal of the Department of Energy's Refrigeration Systems Program, in which ORNL's Buildings Technology Center (BTC) plays a large role, is to develop and market advanced refrigeration systems to reduce the projected energy consumption in U.S. buildings by 10% in 2010. There are several reasons for the current energy reduction goal. They include saving money, reducing reliance on imported oil, and helping utilities avoid risky capital investments in new power plants to meet escalating demands for electricity during certain times of day.

The most compelling reason to curb demand for electricity is to slow global warming. Fossil fuels used for electricity production are a large source of atmospheric carbon dioxide, a greenhouse gas that may alter the climate. Energy use in buildings accounts for 36% of carbon dioxide emissions produced in the United States, suggesting that buildings may have a significant impact on outdoor as well as indoor environments.

ORNL's Role

ORNL has been heavily involved in the refrigerator redesign efforts of the past two decades. Today the Laboratory has the largest and most comprehensive refrigerator-freezer research program supported by DOE. ORNL has the expertise and experience to help meet the challenge of increasing energy efficiency of refrigeration. Since 1977, ORNL's contributions to developments of commercial refrigerator-freezers and other refrigeration equipment include

- Design of more-efficient refrigerator, refrigerator compressor, and supermarket refrigeration systems through collaboration with subcontractor firms;
- Improvement of a computer model of a refrigerator developed by an ORNL subcontractor that is still being used to design energy-efficent refrigerators, including single-door models being built and sold in India;
- Identification of a refrigerant blend that is ozone safe and of a new refrigerator design that allows the blend to be used without loss of energy efficiency; and
- Introduction of a computer model that allows engineers to optimize heat-exchanger designs rapidly to produce efficient appliances.

BTC is now working on developing a highly energy-efficient refrigerator-freezer that uses an efficient and environmentally acceptable refrigerant and insulation. This work is being done under cooperative research and development agreements (CRADAs) with the largest manufacturers in the refrigeration industry.

ORNL also will play a role in DOE's latest effort to save energy. In addition to developing new highly efficient refrigerators, DOE seeks to help industry sell existing energy-efficient refrigeration equipment.

Among the researchers who have led the more recent developments in BTC's $1-million-a-year refrigeration research program are Van Baxter,

Phil Fairchild, Steve Fischer, Patrick Hughes, Keith Rice, Jim Sand, John Tomlinson, and Ed Vineyard, all of the Energy Division, and Tom Kollie, Ron Graves, and Ken Wilkes, all of the Metals and Ceramics Division. Several of these researchers have been influential in their fields.

In three of the past five years, Sand and Vineyard have won American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) technical paper awards; the award recognizes the best papers presented at the annual meetings of the international organization. Vineyard has participated on technical panels for ASHRAE, the Super Efficient Refrigerator Program of the Consortium for Energy Efficiency, the Association of Home Appliance Manufacturers (AHAM), and the United Nations Environmental Programme (which in 1991 and 1994 produced *Technical Progress on Protecting the Ozone Layer*, to which he contributed a chapter). Sand is a member of an advisory committee for the Materials Compatibility and Lubricant Research program of the Air-Conditioning and Refrigeration Institute (ARI), which sponsors research aimed at solving the equipment problems resulting from the use of alternative refrigerants. He also was a panelist for a February 10, 1994, video conference on CFC refrigerant recovery and replacement, which was broadcast by satellite to a wide regional audience in the Southeast.

Baxter was the recipient of ASHRAE's 1982 Willis H. Carrier Award. Fairchild, who helped establish ORNL's research program on CFC alternative refrigerants, is an adviser to ARI's Research and Technology Committee; in 1987 he gave testimony at U.S. Senate Joint Subcommittee Hearings on Stratospheric Ozone Protection and Substitutes for Ozone-Depleting Chemicals. These and other ORNL researchers have also helped steer the refrigeration industry in a new direction through their work as influential members of ASHRAE's Refrigeration Technical Advisory Committee.

Advanced Refrigerator Model and Compressor

ORNL is assisting the effort to develop more efficient but affordable appliances in India and China.

In 1977, ORNL engineers led by Virgil Haynes in the Energy Division were asked by DOE's predecessor agency to work with subcontractor firms to develop a more efficient refrigerator. Funds received by ORNL paid for the work of subcontractors selected by the Laboratory.

In one project, ORNL engineers worked with engineers from Amana, a refrigerator manufacturer, to develop a more efficient refrigerator-freezer. To help them, they used a computer model of a refrigerator developed in 1977 by Arthur D. Little, Inc., under an ORNL subcontract. Amana performed field tests of different models of refrigerators to determine which ones were most efficient. ORNL provided technical guidance and expertise for all this work.

The engineers focused on vapor-compression refrigeration. In this device, a refrigerant under low pressure is evaporated in a coiled pipe called an evaporator. To get energy to evaporate, the refrigerant pulls heat away from the refrigerator compartment, chilling it to the desired temperature. A compressor draws away the evaporated refrigerant, compresses the vapor, and passes it to a condenser, where it gives off the heat it had absorbed to the kitchen air. The increased pressure and loss of heat forces the refrigerant to condense into a liquid. The liquid refrigerant is expanded to the lower pressure, reducing its temperature, and then is returned to the evaporator. Throughout these cycles, a thermostat regulates the temperature inside the refrigerator by switching the compressor on and off.

To design a more efficient refrigerator, Amana and ORNL engineers decided to increase the insulation thickness in the refrigerator's walls from 1/2 inch to 2 inches, install an anti-sweat switch, move the fan to a better location, improve compressor efficiency, and increase heat exchanger areas. They elected to have two evaporators instead of one—one evaporator for maintaining freezer temperature at 0–5°F and the other for holding the refrigerator at 40°F for fresh food. Because electric heaters are used for

Another ORNL-led project reduced electricity consumption in supermarket refrigeration systems.

defrosting, they decided to save additional energy by setting the refrigerator-freezer for automatic defrost every 4 days instead of every 18 hours.

The collaborating engineers showed that refrigerator efficiency could be increased by these changes. Although these changes would raise the cost of the appliance, they argued that the difference could be made up by reduced long-term operational costs through decreased use of electricity.

Amana built and sold a more efficient refrigerator that incorporated these changes. "Its major features were a delayed defrost, increased insulation, and a dual evaporator," says Sand. "But it was on the market for only a few years because it had some moisture problems in the fresh food compartment."

However, the refrigerator model developed under ORNL subcontract and later improved and validated by ORNL researchers is still in use today. It will be used by Indian manufacturers to develop more-efficient single-door refrigerators for India. ORNL is assisting the effort to develop more-efficient but affordable appliances in India and China through a DOE program called Assisting Deployment of Energy Practices and Technologies (ADEPT). For the Indian project, BTC evaluated the energy performance of refrigerators made by five different Indian companies and suggested design changes to improve their efficiency. Improved efficiency is deemed necessary to keep demand for electricity under control in a country that lacks resources for adding power plants. The demand for power will rise because the portion of the population that uses refrigerators is expected to increase from 6% now to nearly 60% by 2010.

In a November 17, 1994, letter to DOE officials, Tom Wilbanks, corporate fellow in ORNL's Energy Division, wrote: "Quite clearly, the ADEPT project is viewed as a major success in India—a model of bilateral cooperation. Besides leading to a new joint venture between Amana and Voltas, it is credited with encouraging Whirlpool's entry into the Indian market (purchasing Frigidaire's share in Kelvinator-India). The results of ORNL's tests of five Indian home refrigerators have led directly to a decision by the Bureau of Indian Standards to [tighten] the voluntary efficiency standard for Indian refrigerators. . . . In addition, the Indian Institute of Technology (IIT) has added an environmental chamber to its refrigeration R&D lab as a direct result of [an IIT professor's] participation in the April 1994 workshop in Oak Ridge and his observation of ORNL's testing approaches."

A related project in the late 1970s that was an unusually big success was the development of a more efficient refrigerator compressor by engineers from industry. ORNL was technical monitor for this project with Columbus Products, which later became White Westinghouse and then Americold Compressor Company. In 1981, the subcontractor, by incorporating design changes to the motor, suction muffler, and compressor valve assembly, developed a compressor that uses 44% less energy than conventional units of the same size. The compressor is part of product lines of Americold Compressor and Frigidaire. This compressor technology has helped reduce annual refrigerator energy use from 1500 kilowatt hours (kwh) to 900 kwh per year in 1990. Between 1980 and 1990, according to DOE, the energy-efficient refrigerator compressors saved U.S. consumers $6 billion in energy costs. The more efficient compressor is one of three achievements cited as "notable successes" in DOE's 1991 *Refrigeration Systems Program Summary* report, and it was recently awarded a DOE Pioneer Award.

Another ORNL-led project that received a DOE Pioneer Award resulted from a collaboration of the Laboratory's Energy Division and Foster-Miller Associates (FMA), H. E. Butt Grocery, and Friedrich Commercial Refrigeration. The project goal was to reduce electricity consumption in supermarket refrigeration systems, which use nearly 2% of the electricity consumed in the United States. The research led to improvements in refrigeration systems that cut energy use in U.S. supermarkets by 30%, reducing energy bills by about $4 billion since the mid-1980s. About 80% of supermarkets now use the advanced system.

An improved microprocessor controller that modulates the compressor capacity to meet changing refrigeration loads accounted for about half of the efficiency gain. The remaining

Ed Vineyard checks instrument readings during a test of chlorine-free refrigerant mixtures and alternatives to the coolant HCFC-22.

improvement came from further refinements developed by manufacturers sponsored by the Electric Power Research Institute. In addition to cost savings, the reduced energy consumption by supermarkets avoided the emission of almost 10 million metric tons of carbon.

Concern about CFCs

After development of a computer model and a more efficient refrigerator and compressor by 1981, refrigerator research at ORNL lay dormant for 6 years. Then in 1987–88, the CFC issue emerged because of concern about the thinning ozone layer. Suddenly, funding became available from DOE to develop CFC-free insulation and CFC-free refrigerants for refrigerators.

During this time, DOE's Roof Research Facility at ORNL was dedicated as a national user facility to help industry develop longer-lasting energy-efficient roofs. Soon after, this facility became concerned with developing and testing CFC-free roof insulations. It added a room with apparatus for evaluating the energy performance of CFC-free insulations and CFC-free refrigerants for refrigerators, air conditioners, and heat pumps.

In 1993, the user facility was renamed the Buildings Technology Center. Researchers from industry used this center not only for roof research but also for development of more-efficient appliances. Just as ORNL's early refrigeration researchers had collaborated with industrial firms through subcontracts, the Laboratory's current researchers became involved with the refrigeration industry through collaborative agreements and CRADAs. The focus of these agreements has been energy-efficient, environmentally acceptable refrigerators and other refrigeration equipment.

The problem is that CFCs contribute not only to ozone depletion but also to global warming.

Concern about Global Warming

In June 1992, the international Earth Summit meeting was held in Brazil. Concerns about global warming were strongly expressed, and the United States was urged to reduce its emissions of carbon dioxide. The U.S. pledge to restrict carbon dioxide emissions through increased energy efficiency and other measures was formulated in President Clinton's Climate Change Action Plan of 1993. This plan exerts additional pressure on the refrigeration industry to design, manufacture, and market energy-efficient appliances that use environmentally acceptable refrigerants and insulations. In addition, the Energy Policy Act of 1992—legislation passed by Congress that was based on information gathered for DOE's National Energy Strategy—gives DOE the authority and responsibility to pursue energy efficiency actively.

Emphasis should be placed on improving energy efficiency of refrigerators to reduce carbon dioxide releases.

The problem is that CFCs contribute not only to ozone depletion but also to global warming. In fact, their contribution to global warming is second only to that of carbon dioxide, which accounts for 80% of greenhouse gas emissions in the United States. However, replacing CFCs with ozone-friendly compounds such as hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) would still affect global warming. HCFCs and HFCs are also greenhouse gases, but their direct impact on global warming is much smaller than that of CFCs. However, widespread use of some CFC alternatives in refrigeration systems would result in larger consumption of electricity from fossil fuel plants. Thus, emissions of carbon dioxide would increase, speeding up global warming. Clearly, the substitute refrigerants would have an *indirect* impact (energy-related) as well as a *direct* impact (emission-related) on global warming. The combined effect is called the total equivalent warming impact (TEWI).

The concept of TEWI and of indirect and direct effects of greenhouse gases on global warming was developed by Steve Fischer, Patrick Hughes, and Phil Fairchild, all of ORNL's Energy Division, and analysts from Arthur D. Little, Inc., for the first CRADA at the Laboratory. The agreement involved ORNL and the Alternative Fluorocarbons Environmental Acceptability Study, a consortium of 12 of the world's largest producers of fluorocarbons. The work was started in December 1990 and completed in December 1991 with the publication of *Energy and Global Warming Impacts of CFC Alternative Technologies*.

Under the CRADA, ORNL evaluated the relative performance, subsequent carbon dioxide emissions, and net global climate change potential of CFC alternatives in building energy-related applications. ORNL investigated alternative refrigerants; insulation materials and systems; and advanced refrigeration, air-conditioning, and heating technologies. Consortium members contributed technical expertise on refrigerant alternatives. The CRADA was extended and a second report was issued in December 1994. The extension focused on investigating several alternative technologies to fluorocarbon-based vapor-compression refrigeration.

"The direct effect on global warming of a refrigerant leaking from refrigerators is less than the indirect effect on global warming of carbon dioxide from their energy use," Sand says. "For leaking automobile air conditioners, the direct effect of the leaks on global warming is larger than the indirect effect of burning gasoline. But for refrigerators the indirect effect of consuming electricity inefficiently from fossil fuel plants is much larger than the direct effect of refrigerant leaks. So, for environmental reasons, emphasis should be placed on improving energy efficiency of refrigerators to reduce carbon dioxide releases."

Environmentally Acceptable Refrigerants Identified

In 1990, ORNL researchers tested DuPont refrigerant blends proposed as substitutes for R-12, the commonly used refrigerant that contains CFCs. They identified an HCFC blend of R-22/R-152a/R-124 as an ozone-friendly chemical that could be even more energy efficient than the

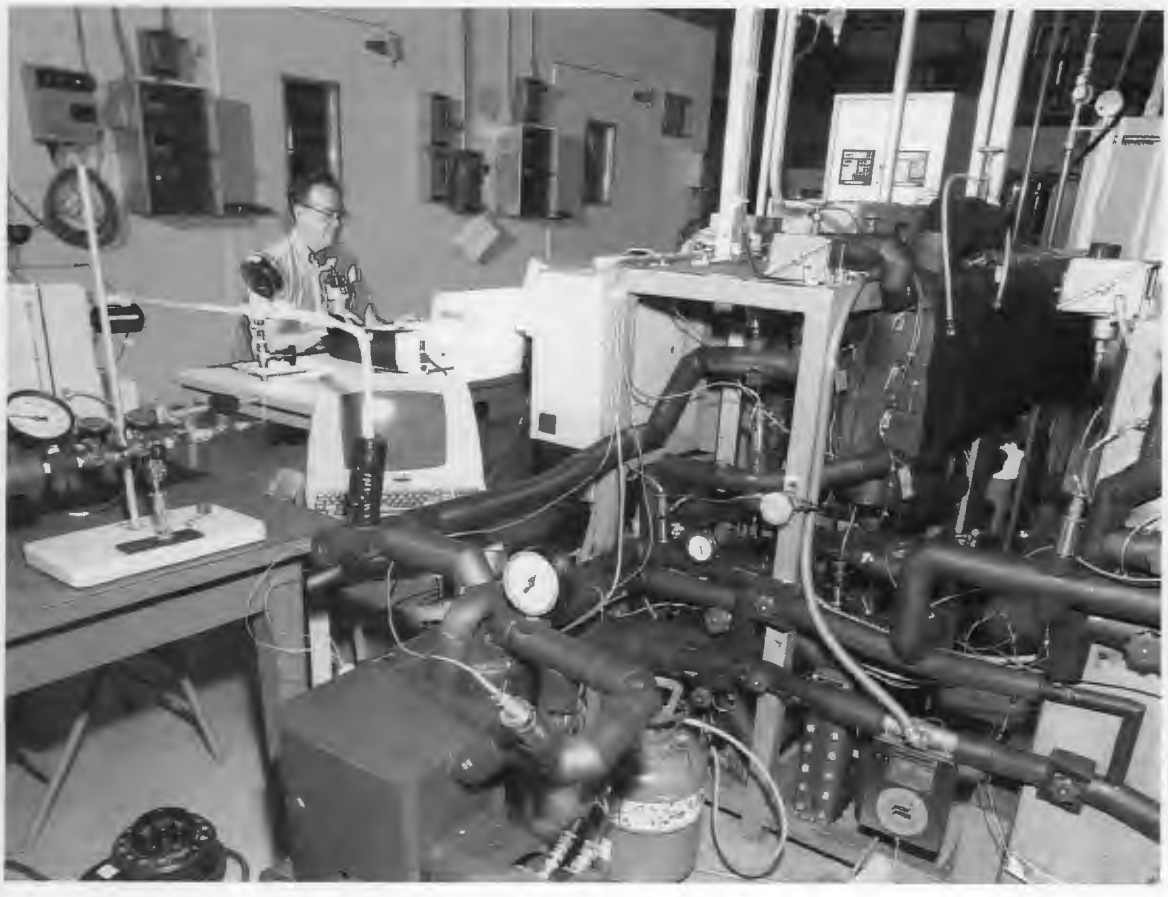
common refrigerant R-12 if the refrigerator were properly redesigned to increase heat transfer and improve the refrigerant circuit arrangement.

"We helped DuPont make its refrigerant blend more efficient," Ed Vineyard says. "DuPont made the blend using the results of our computer model. We tested this blend and many other HCFC blends. We suggested changes in the blend's composition to improve its efficiency. DuPont made the changes, and we wrote scientific papers on the new blend."

The ORNL researchers had tested numerous alternative refrigerants supplied by DuPont and Pennwalt using the Laboratory's Alternative Refrigerants Calorimeter Facility. In examining each refrigerant, they measured its energy performance (the electrical energy required to operate the appliance using the refrigerant) and its refrigeration capacity (the ability of the fluid to absorb heat—a measure of the cooling output). The ratio of the refrigeration capacity to the electrical energy input is the coefficient of performance (COP). The alternative refrigerants that have the highest COPs were considered the best candidates for future refrigerators.

Vineyard, Sand, and others have used a computer model of a detailed refrigerator system to evaluate the energy savings for several design modifications of a refrigerator using an alternative refrigerant such as HFC R-134a. The design options included use of a more efficient compressor, increased evaporator and condenser size, door gaskets to reduce energy losses, improved cabinet and door insulation, and high-efficiency fan motors. Laboratory refrigerator prototypes were built and tested to verify the model's analytical results experimentally. The modeled and experimental results were generally

We helped DuPont make its refrigerant blend more efficient.



Charlie Hardin (now retired) sets up a breadboard refrigeration loop to test heat transfer performance of zeotropic mixture alternatives to HCFC-22.

in agreement. The differences observed guided the researchers in improving the model.

Partly as a result of the influence of ORNL researchers Sand and Vineyard on AHAM's Refrigeration Technical Advisory Committee, the refrigeration industry adopted R-134a as the refrigerant of the future.

" Just as you must switch from an internal combustion engine to a diesel engine if you want to use diesel fuel instead of gasoline," Sand says, "we found that the refrigerator design had to be changed to use R-134a as a refrigerant."

Hydrocarbon refrigerants have one problem. They are flammable.

"It is not easy to change from a refrigerant used for 40 years," Vineyard says. "To use 134a, the refrigerator had to be redesigned in a short time because after 1995 it will be illegal to build a refrigerator that uses only R-12 because this refrigerant will be phased out."

"We faced several complications in the rush to redesign the refrigerator for the new refrigerant," Sand says. "For example, we learned that the conventionally used lubricating oil is not compatible with 134a. So we tried a different oil. But we found out that this oil dissolves insulation for the compressor motor, causing it to burn out. So we tried a different oil, but it plugged up the expansion valve. As you can see, the ripple effect of one change necessitates a cascade of changes that jacks up the cost of the refrigerator."

Because of these problems, DOE and the Air-Conditioning and Refrigeration Technology Institute are jointly funding research to determine the compatibility of structural materials and lubricants with refrigerants being considered as replacements for restricted CFC compounds.

"Some environmentalists complain that the refrigeration industry is slow to manufacture environmentally sound refrigerators," Sand says, "but the reason for the delay is that it takes time to develop and test a system that accommodates a change in refrigerants. If enough time is not taken to conduct tests, a financial disaster could occur. Recently, a leading manufacturer of refrigerators lost almost a billion dollars replacing damaged refrigerators. For these new models, the company had decided to use a new compressor design. But the new compressors failed in consumers' homes after a few weeks of operation, so the company lost a considerable amount of money."

HFCs such as R-134a have been favored over CFCs because they are less of a threat to the ozone layer. However, HFCs have since fallen into disfavor in some quarters because they are greenhouse gases that have long atmospheric lifetimes. R-134a absorbs infrared radiation emitted by the earth's surface in the spectrum not absorbed by other gases.

"The ultimate refrigerant of the future," Sand says, "could be hydrocarbons like isobutane or propane if HFCs fall victim to global warming concerns. Hydrocarbons are 4 to 5% more efficient than R-12, they don't destroy the ozone layer, and they don't contribute to global warming. Isobutane is a propellant used to replace CFCs in spray cans, and propane is found in crude petroleum and natural gas. European refrigerator manufacturers are now switching to hydrocarbons."

"Hydrocarbon refrigerants have one problem," Vineyard says. "They are flammable. That's why hydrocarbons, which are natural refrigerants, were not originally selected for electric refrigerators. Vendors will have to deal with lawsuits that may arise from expected increases in refrigerator-related house fires. They will have to worry about the risk of fire in factories that store hydrocarbon refrigerants and in hydrocarbon tanks in trucks used by refrigerator service people. To reduce the fire risk to homeowners, we will have to engineer around such refrigerants and keep them hermetically sealed. But there will always be a small risk that they could leak out into defroster heaters or catch electrical sparks and ignite. We hope to study these problems for the Environmental Protection Agency."

Friendly Insulation

R-11, an insulation blowing agent that contains CFCs, was once used to blow polyurethane foam into refrigerators. Now HCFC-141b, which contains chlorine, is used as the common blowing agent; the problem with it is that chlorine can attack the ozone layer. Today the goal is to

Refrigerator of the future.

ORNL researchers are now measuring the lifetime and thermal resistance of vacuum insulation samples.

insulate new refrigerators with a combination of vacuum insulation and foam blown with a non-ozone-depleting chemical. "This combination," says Ken Wilkes, "is expected to be very efficient but more expensive and with uncertain reliability."

Two types of vacuum insulation being developed and tested at ORNL are powder evacuated panels (PEPs) and an insulation that contains fibrous glass. Because the insulating value of these materials is several times greater than current refrigerator insulation, they could save $10 to $20 a year in electricity per unit. But vacuum insulations are more costly than foam insulation.

In vacuum insulations, powder or fiber is sealed in evacuated envelopes. "Vacuum insulations," says Wilkes, "are like boxes of coffee grounds packed in vacuum except the grounds are insulating powders or fibers and the packages are made of plastic or steel sheets."

In 1981 Arthur D. Little, Inc., and ORNL looked into developing vacuum insulations for refrigerators, ovens, and mobile homes to improve energy efficiency. At ORNL, David McElroy made laboratory measurements of properties and performance of materials in vacuum insulations. He determined the insulating value of the fine powders and the ability of evacuated envelopes of different materials to support the load of the atmosphere without collapsing.

For vacuum insulations, durability is a key issue. If they are not durable, they develop holes and air leaks in, destroying the vacuum. In addition, air molecules can diffuse through plastic envelopes, even if they have no holes. In some Japanese refrigerators, vacuum insulations have been known to lose their vacuum in a year. They

must be made durable for 15 to 20 years, the expected lifetime of refrigerators.

At ORNL, Tom Kollie (now retired from the Metals and Ceramics Division) developed a procedure for measuring the lifetime of various vacuum insulations. ORNL researchers are now measuring the lifetime and thermal resistance of vacuum insulation samples. They are developing computer models to account for heat flow around the panel edges. In general, they have found that the thermal resistivity of vacuum insulations exceeds that of conventional insulation by 3 to 7 times, or more.

ORNL researchers are now working to design a new refrigerator-freezer that is 50% more efficient.

Evacuated panels contain fibrous glass or ceramic or metallic powders. Vacuum insulation jackets are made of plastic sheets or steel foils. They will be embedded in foam in the refrigerator door and wall. From the outside in, the refrigerator of the future may consist of a steel skin, vacuum insulation panels about 1 inch thick, about 1 to 2 inches of insulating foam blown with a non-ozone-depleting chemical instead of a chlorine-containing agent, and a plastic inner wall. The foam will give the steel wall structural rigidity.

Currently, ORNL researchers are evaluating vacuum insulations under CRADAs with PPG, Aladdin Industries, DuPont, VacuPanel, and the AHAM, which represents all major refrigerator manufacturers ranging from Amana to General Electric to Whirlpool. The goal of the research is to develop fillers and vacuum envelopes that offer increased thermal resistivity and longer lifetimes while decreasing cost.

Fridge of the Future

ORNL researchers are now working under a CRADA with the Appliance Industry–Government CFC Replacement Consortium, a subsidiary of AHAM. The goal of the CRADA is to design a new refrigerator-freezer of conventional size by 1998 that is 50% more efficient than the 1993 federal standard. This "next-generation" refrigerator must use environmentally acceptable materials.

Some of the innovative concepts being investigated by engineers from ORNL and the refrigeration industry include highly efficient adjustable-speed compressors, dual-evaporator refrigerators, compact heat exchangers, advanced insulations, and refrigerant blends. The "fridge of the future" is expected to have PEPs and foam insulation, extended surface heat exchangers for the condenser and dual evaporator, an environmentally friendly refrigerant, direct-current electrically commutated motors for the two fans that blow air past the condenser and dual evaporator, and an expansion valve.

The refrigerator firms have proposed changes and sent their best components and improved versions to ORNL for testing. ORNL tests units containing the best components from the different companies. ORNL then gives participants test results and suggests changes to further improve component and refrigerator design.

A new CRADA is being negotiated between ORNL and an undisclosed large refrigerator

Bill Miller inspects a facility for testing heat exchanger designs for advanced heat pump systems.

manufacturer. The goal is to develop the most energy-efficient unit using advanced door gaskets (with better seals to reduce energy losses), improved defrost, advanced insulation, and a different evaporator-compressor-condenser cycle.

Helping Designers of Heat Pumps

ORNL research has had an impact on the development of more-efficient heating and cooling equipment as well as refrigerators. This equipment includes gas-fired and electric-driven heat pumps.

In the 1980s, C. Keith Rice together with Steve Fischer and other staff in ORNL's Energy Division developed a computer model that has become a valuable tool for heat pump designers. The model allows designers to determine the effects of newly designed individual system components on performance of new heat pump and air-conditioner designs. The ORNL computer code has been widely used by U.S. manufacturers to design highly efficient air-to-air heat pumps and air conditioners. The Trane Company uses the model together with its own expert system to cut component design time by 75%. According to DOE, application of this model has contributed to the development of heat pump systems that use 20% less energy than conventional systems. This development is another of the three achievements cited as "notable successes" in DOE's 1991 *Refrigeration Systems Program Summary* report.

ORNL also manages a program for DOE that has guided industry in producing more-efficient heating and cooling equipment. A new technology that doubles the efficiency of gas heating—a gas-fired heat pump called the GAX system—has been developed. ORNL engineers are working with a leading company and gas utilities to market this technology (see the following article).

Marketing Efficient Appliances

Developing highly efficient appliances is not the only way to reduce appliances' use of energy. Another way is to increase sales of appliances already on the market that are "energy savers." These include $1200 refrigerators that will save buyers $1200 over 10 years in electricity costs.

"DOE is focusing more on helping vendors sell their efficient appliances than on developing new ones," Sand says. "This is the softer side of DOE. It is selling the sizzle rather than the steak."

"The DOE sticker will be on future appliances to lend credibility to vendors' claims that energy savings from a product will eventually pay for its initial cost," Vineyard says. "Because DOE has name recognition and a reputation for energy expertise, appliance vendors want DOE's name on their efficient products to help them sell. DOE wants to help the vendors because it knows that convincing consumers to replace yesterday's inefficient appliances with today's more efficient ones will save energy."

The DOE sticker will also be useful to salesmen and customers. It will help them identify the high-efficiency appliances for which some electric utilities give rebates.

The refrigerator of the future will likely also bear a DOE sticker because it will use half as much energy as today's refrigerator. Saving energy benefits many groups. Consumers enjoy lower electricity bills and may use their savings to buy other products, stimulating the economy. Commercial and industrial firms using more-efficient refrigeration equipment may use their savings to hire more workers. Electric utilities may be able to avoid building new power plants. The nation has less of a need to rely on imported oil for electricity production. And, environmentalists and policymakers have less concern that refrigerators will contribute to thinning of the ozone layer and to global warming. In short, the refrigerator of the future will be environmentally acceptable. It is hoped that it will keep our food cold without making the globe too warm. ornl

ORNL developed a computer model that has become a valuable tool for heat pump designers.

New Gas-fired Heat Pump Technologies Help Chill Greenhouse Effect

By Bill Cabage

"Shut the door! Are you trying to warm the whole world?"

ORNL is helping to develop an advanced heat pump technology that would eliminate CFCs and use 50% less energy to heat and cool buildings.

Everyone's been fussed at for lingering too long in a doorway. In a way, Mom may have been right all along. As we warm and cool the interiors of our buildings, there's a risk we might warm our climate. It all has to do with our use of fossil fuels as an energy source. ■ Air conditioning and space heating account for 46% of the energy used in U.S. buildings. Air conditioning is the single leading cause of peak electric power demands. Much of this building energy comes from combustion of fossil fuels, a major source of carbon dioxide—a greenhouse gas. Air conditioning and space heating are also sources of ozone-depleting chlorofluorocarbons (CFCs), which are also greenhouse gases. They are called greenhouse gases because they prevent heat energy reflected from the earth's surface from escaping the atmosphere. In theory, that trapped heat could cause global warming, which many scientists believe is already occurring. ■ Advances in energy conversion technologies offer a solution to this problem. DOE, ORNL, and its industrial partners are focusing on an advanced heat pump technology that would eliminate CFCs and use 50% less energy to heat and cool buildings. Such an energy savings would avert an increase in carbon dioxide and other emissions that would occur from increased power generation by fossil-fueled power plants.

DOE's Office of Building Technologies has selected a technology first patented in 1913 and developed further under DOE sponsorship and ORNL oversight in the 1980s. Called the generator absorber heat-exchange cycle, this absorption heat pump is powered by electricity and natural gas. It does not use a compressor or ozone-depleting CFC refrigerants. Instead, it uses environmentally safe refrigerants that release heat energy when mixed, increasing its thermal efficiency.

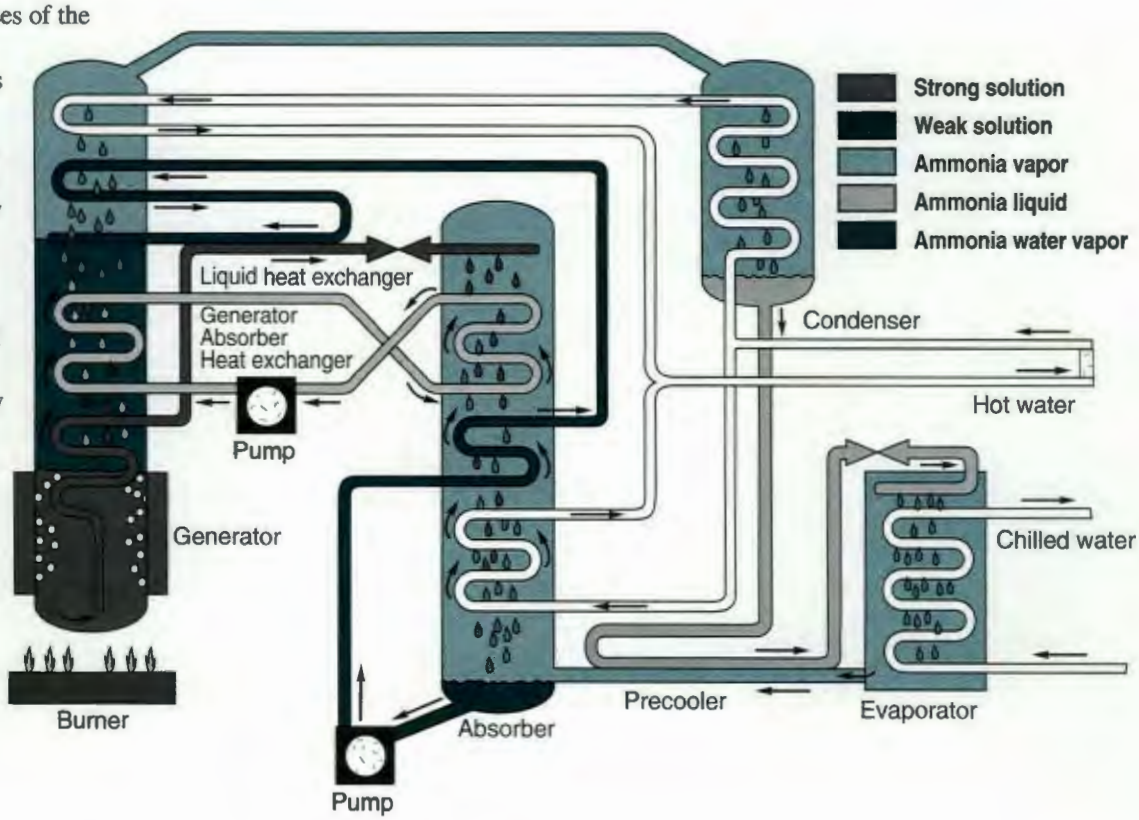
Getting cool air by heating something over a flame is no new trick. The principles of heat absorption have been known for a couple of centuries. Although heat pumps have been in use for decades, making efficient ones has been a continuing technical challenge. The single-effect absorption heat pump—consisting of a single loop containing a generator, compressor, evaporator, and condenser—works fine, except it's expensive considering the output relative to the energy going in.

When the energy crises of the 1970s had Americans scrambling to find ways to heat and cool their homes more efficiently, natural gas—cheap and abundant—took on new promise as a fuel. ORNL's Thermally Activated Heat Pump Program set out in 1981 to find ways to maximize the efficiency of gas-fired designs through the Advanced Absorption Cycle Program, which was initially planned by Bob DeVault of the Energy Division.

"For residential use, the generator-absorber heat exchange, or GAX,

Defying Gravity: How the GAX works

A flame from the natural gas burner heats a sealed pot containing a mixture of refrigerant and absorbent solution such as ammonia and water. The refrigerant is boiled out. Because the refrigerant—the ammonia—is in an enclosed chamber, heating also raises its pressure. The high-pressure ammonia vapor is then condensed, extracting heat from the refrigerant. The condensed refrigerant travels to the low-pressure evaporator, where the liquid refrigerant picks heat up from the environment—the cooling effect—and is turned once again into vapor, except now at low pressure and temperature. At the same time, the absorbent (water) from the generator, after the refrigerant is boiled out, travels to another heat exchanger called the absorber, which is at low pressure. The refrigerant vapor from the evaporator is next recombined with the water in the absorber. This recombining of the ammonia refrigerant and the water absorbent involves a chemical reaction that produces heat. This heat is removed from the absorber to increase GAX's thermal efficiency, and the now cool low-pressure mixture is pumped back to the generator, completing the process.



heat pump has been DOE's number one priority," DeVault says. In the gas-fired GAX, a chemical process substitutes for the motor-driven compressor. The GAX has its advantages: Instead of using ozone-depleting refrigerants common to electric systems, the gas-fired systems use environmentally benign natural refrigerants such as ammonia and plain old water. You can reverse the gas heat pump output to provide air-conditioning: Cooling with gas in the summer would reduce big-city brownout threats during heat waves.

The next big step is the triple-effect chiller, which takes efficiency one stage further.

The GAX heat pump's goal is to make heat generated in its process productive. "GAX is more than an acronym; the X is also symbolic of the actual heat exchange process involved," DeVault says. Heat from the absorber is recycled to the generator tank, increasing its efficiency. However, this heat-recycling process is difficult to achieve because the gravity-driven chemical processes are "upside down" from the ideal process needed to enable satisfactory exchange of the heat from the absorber to the generator. "The X in GAX" says DeVault, "is symbolic of inverting the thermal gradient—defying gravity, so to speak."

DeVault issued the first request for proposal for what became GAX in 1982. The system, largely developed by a small business firm, Phillips Engineering, under subcontract to ORNL, was licensed to Carrier Corporation in 1993. According to subcontract manager Patti Adcock, the cost-sharing in the project has been substantial. The GAX, she says, should be making an impact on the residential market in the next few years, primarily in northern markets because its greatest efficiency gain is in heating. A GAX unit is about the size of a conventional heat pump.

A new area, barely out of the dream stage, is called "high cool." It's the next step beyond the GAX for residential and small commercial use. The high-cool goal is a 30% gain over the GAX in cooling. DeVault explained the quest for even greater efficiency: "The GAX is very efficient at heating but only average at cooling, which makes it most attractive to northern markets. In light of that, however, a GAX could heat and cool a house for what a gas furnace operates at now just to heat the house." High cool will build on these efficiency gains.

The GAX technology is aimed at residences. Larger buildings are often cooled with systems called chillers. For the big commercial chillers, which chill water that in turn cools the building, the triple effect appears to be the wave of the future. Single- and double-effect chillers have been sold for years. Double-effect chillers add a second generator and condenser that recycles some of the process heat, increasing efficiency.

"The next big step is the triple-effect chiller, which takes efficiency one stage further," DeVault says. Although the increased sophistication and complexity of the triple-effect system will require a cost premium of 25% or more (competitive pricing is also a goal of these programs), the triple-effect chiller's goal is a 40 to 50% gain in efficiency. "Because a triple-effect system runs at higher temperatures, it requires new chemistry and new materials to resist the corrosion that accompanies high temperatures. Many of the technologies to deal with those challenges have been invented at ORNL."

All of the large U.S. heating and air conditioning companies are participating in the national partnership to develop the triple-effect chiller. One triple-effect technology invented at ORNL has been licensed to the Trane Company for marketing and development. A second, different ORNL technology is being developed by York International under a cost-shared subcontract with DOE.

The Efficiency and Renewables Research Section in ORNL's Energy Division has been developing the required new technologies in step with these projects. An absorption simulation computer modeling program will take much of the time and tedium out of modeling new heating and cooling schemes. "Before, you had to write them out from scratch," DeVault says. "Now you can use this model to change a system or operating condition by pulling equations out of a data bank. It also features a graphical interface." Gary Grossman initially wrote the program and Steve Fischer is continuing the work. "Our sponsor is really proud of it, and it's not even finished yet."

Abdi Zaltash and Delmar Fraysier, both of Energy Division, are investigating advanced absorption fluids that work better than water with ammonia or lithium bromide. Much of the magic in cooling with gas lies in better refrigerant and absorbent combinations. "One issue for large commercial chillers is developing additives that accelerate heat and mass transfer," DeVault says. "Also, with the triple effect, corrosion caused by the high temperatures is a factor."

Bill Miller of the Energy Division has investigated lithium bromide and water falling-film absorption systems for several years. His original research, which featured a vertical column, concentrated on quantifying heat and mass transfer that occurred in a falling-film absorber. Although falling-film absorption systems have been used for decades, most designs ignored mass transfer—data for heat- and mass-transfer modeling were not available. The Gas Research Institute, the sponsor, was impressed enough with ORNL's work to fund studies toward industrial applications—double- and triple-effect chillers. As a result, the tall vertical absorption column, designed to be compact enough for residential use, took on a more conventional horizontal layout.

That work has been successful; Jerry Atchley and Miller have characterized 12 different tube surfaces for a falling-film absorber system. Two of the surfaces, donated by Wolverine Tube, Inc., improve performance comparable to alcohol additives. "Alcohol in small amounts will double performance, but it is difficult to control in these triple-effect, high-temperature systems," Miller says. "Advanced surfaces would eliminate design problems with alcohol and would improve system reliability."

Why has the Thermally Activated Heat Pump Program become so heavily involved with the HVAC industry? As DeVault explains, one reason is the Energy Policy Act of 1992, which authorizes labs to work with industry and requires programs to be cost-shared, "which industry has been willing to do." Working with industry adds the aspects of demonstration and commercialization to R&D.

Another reason could be global competitiveness. Japanese makers now dominate the world market for large commercial absorption chillers. Although the double-effect chillers were pioneered in the United States, the U.S. makers were slow to manufacture them, and now most of the double-effect chillers made by U.S. companies are licensed Japanese technologies. The triple-effect chiller could give the United States a jump in the global market.

The environmental benefits are important. More efficiency means reduced energy consumption and related emissions. Natural gas is our "cleanest" fossil fuel, and instead of using ozone-depleting refrigerants, absorption chillers use natural refrigerants—ammonia or water. In most cases, especially compared with natural gas furnaces or coal-fired electric generating plants, they will substantially reduce carbon dioxide and nitrous oxide emissions to the atmosphere. ornl

Instead of using ozone-depleting refrigerants, absorption chillers use natural refrigerants—ammonia or water.

AWARDS & APPOINTMENTS

Gerald Mahan

Robert Compton

Herbert Mook

Gerald D. Mahan, ORNL–University of Tennessee Distinguished Scientist, has been elected to the National Academy of Sciences.

Robert Compton and **Herbert A. Mook** have been named senior corporate fellows and **Malcolm Stocks** has been named a corporate fellow by Lockheed Martin Energy Systems.

C. H. (Winston) Chen and **Robert J. Warmack** have been elected fellows of the American Physical Society.

Linda Cain has been named director of ORNL's Office of Science Education.

George Courville has been named associate director of ORNL's Energy Division.

Michael R. Strayer has been named a distinguished visiting professor in the Department of Physics and Atmospheric Science at Drexel University in Philadelphia.

Phillip F. Britt has received the Richard A. Glenn Award for the outstanding paper presented at last fall's meeting of the American Chemical Society's Division of Fuel Chemistry.

Lee Shugart has been named a member of the editorial board of *Biomarkers*, a new scientific journal.

Robert V. O'Neill has received the 1995 Award for Distinguished Landscape Ecologist from the U. S. Regional Chapter of the International Association of Landscape Ecology.

R. J. Michael Fry has been selected as the 32nd Failla Memorial Lecturer of the Radiation Research Society.

Richard Hicks has been named director of the Office of Computing and Network Management.

Douglas R. Bohi has been appointed senior research scientist for economic policy in the Energy Division.

Tuan Vo-Dinh has been named a member of the editorial board of the new *Journal of Biomedical Optics*.

Glenn F. Cada has been appointed to the Office of Technology Assessment's Advisory Panel on Technologies to Protect Fish at Dams.

John Sheffield has been named director of Energy Technology Programs at ORNL. In this newly created position, Sheffield will be responsible for activities in energy efficiency and renewable, fission, fossil, and fusion; energy; transportation programs; and programs in support of the Nuclear Regulatory Commission.

James F. Mincey has been named head of the Nuclear Criticality Safety Section of ORNL's Office of Operational Readiness and Facility Safety.

Kathy Hylton has received the AEG/Modicon Rising Star Award from the Industrial Commuting Society for her achievements in improving the use of computers for factory automation.

Jacqueline Grebmeier has received the Distinguished Scientific Achievement Award from the East Tennessee Chapter of the Association for Women in Science for her research in Arctic ecology.

Dianne Gates, Robert Siegrist, and **Steven Cline** received first-place recognition for a poster presentation entitled "Laboratory Evaluation of the

Malcolm Stocks

Linda Cain

Robert V. O'Neill

In Situ Chemical Oxidation of Contaminated Soils" at the Water Environment Federation's 67th annual conference.

Ellis J. Jackson has received the Total Cost Management Award of Excellence from the East Tennessee Section of the American Association of Cost Engineers International.

Robert Compton has been selected as the recipient of the 1995 William F. Meggers Award of the Optical Society of America.

Pat Scarbrough-Luther has been elected to chair the Southeast Regional ARC/INFO User's Group.

John C. Miller has joined the editorial advisory board of the *Journal of Physical Chemistry.*

Ann M. Shirley has been appointed director of the Office of Safety and Health Protection.

John W. Wooten has been appointed to the adjunct faculty at the University of Tennessee, Knoxville. He will teach a new course focusing on introducing networking technologies into K–12 classrooms.

Samuel McLaughlin has been selected as the first faculty fellow in the natural sciences at Hampden-Sydney College.

The Environmental Sciences Division has presented its 1994 Scientific Achievement Award to **Michael Huston** for his work in the area of global patterns in biological diversity. This work culminated in Huston's 1994 book *Biological Diversity,* a synthesis of ecological research conducted over the past century.

Richard F. Winterfield has been elected state representative to the Southeast Region Arc/Info Users' Group.

Patrick J. Mulholland has been appointed chairman of the executive committee of the North American Benthological Society.

John S. Wassom has been appointed chairman of the Communications and Archives Committee and the Technical Committee of the Environmental Mutagen Society.

Roger Earl Stoller has been chosen to receive the 1995 Award of Merit and honorary title of fellow from the American Society for Testing and Materials.

Stephen H. Stow has been appointed a member of the Strategic Planning Committee for the American Geological Institute.

Timothy C. Scott has been named director of ORNL's Bioprocessing Research and Development Center.

Greg R. Gruzalski has been appointed technical assistant to the Physical Sciences and Advanced Materials Directorate and the Advanced Neutron Source Directorate, replacing **Thomas M. Rosseel**, who is the Energy Research Laboratory Technology Applications program manager with ORNL's Office of Science and Technology Partnerships.

Robert S. Turner has been appointed deputy director of ORNL's Center for Global Environmental Studies.

Don Bible

Rich Leggett

Doug Lowndes

The video "ORNL: Safety Dance" received the Best of Show Award and a Distinguished Technical Communication Award in the International Technical Video Competition sponsored by the Society for Technical Communication (STC). The coordinator for the video was **Diana Linville**. Another of the competition's 15 awards went to **Jon Jefferson**, who worked with Jester-Proud WriterProducers to make the ORNL video *Bringing Science to Life*. This video received an award of merit in the public relations category. In STC's International Technical Publications Competition, an award of achievement in trade/news articles went to **Jim Pearce, Carolyn Krause,** and **Vickie Conner** for "ORNL's Magic Bullets: On Target for Health," *ORNL Review*. In STC's International Technical Art Competition, **John Cook** and **Sandra Schwartz** received an award of achievement in informational brochure design for *Life Sciences for the 21st Century*, and **David G. Cottrell** and **Robert L. Schenley** won an award of excellence in mechanical illustration, tone, for *Tumbler for Zero-Headspace Extractor*.

An ORNL entry in the 1995 Ceramographic Competition of the American Ceramic Society won a first-in-class award in the optical microscopy category. The entry "Surface Blister Formation on Cobalt-Implanted Alumina" is by **Lynn Boatner, Laurence Gea,** and **Mary Jane Gardner**.

Fang C. Chen and **Vince Mei** have earned the Advanced Technology Award from the Inventors Clubs of America's International Hall of Fame for their invention of a liquid-overfeeding air conditioner, which is projected to use 20% less fuel for air conditioning automobiles.

ORNL's **Tower Shielding Facility** (TSF) was recently recognized by the American Nuclear Society as a National Nuclear Historic Landmark. The TSF, which was shut down in late 1992 after 38 years of dedicated support to the U.S. and international shielding community, provided valuable data for the development of radiation shielding methods and the validation of shield designs for virtually every DOE advanced reactor program.

Frederick Schultz has been named an adjunct faculty member at Western Kentucky University.

Ajay K. Rathi has been appointed to the editorial advisory board of the American Society of Engineers' *Journal of Transportation Engineering* and to the Transportation Research Board's Committee on Traffic Signal Systems.

Keith F. Eckerman has received a Distinguished Scientific Achievement Award from the Health Physics Society.

ORNL researchers who received top honors at the annual Energy Systems Awards Night for 1995 were **Don Bible, Rich Leggett,** and **Doug Lowndes**. **Bible** was named Inventor of the Year for developing the Variable Frequency Microwave Furnace, which is used for microwave heating, plasma processing, and other microwave-assisted processes.

Leggett was recognized as the Author of the Year for his paper "An Age-Specific Kinetic Model of Lead Metabolism in Humans," which describes a new, detailed pharmaco-dynamic model for lead that unifies experimental, occupational, and environmental data on the toxin. **Lowndes** was recognized as Scientist of the Year for the discovery of a pulsed-laser method for growth of compound semiconductor thin-films and heterostructures with doping and continuously variable composition. Other Energy Systems employees who won top honors were **Alex Riedy**, recognized as Manager of the Year for his leadership of Project Sapphire, a mission to prepare and undertake the safe packaging and transfer of highly enriched uranium from Kazakhstan to to the Oak Ridge Y-12 Plant; and **Dennis Cope**, who won the Operational Improvement Award for leadership of the Pond Waste Management Project, under which the repackaging of 33,000 steel drums was completed three months ahead of the approved schedule and six months ahead of the original schedule submitted to the Tennessee Department of Environment and Conservation. Other ORNL employees recognized at Energy Systems' Awards Night for their outstanding achievements are listed below with their citations.

Operations and Support Awards for direct provision of exceptional administrative, technical or operational services in support of the missions and programs of Energy Systems were given to **Kathleen R. Ambrose** (ORNL) for outstanding leadership in establishing goals for and in management of the ORNL Animal Care and Use Committee, ensuring that ORNL life sciences research meets all required guidelines; **Sylvia Hurt Arow, Lynn D. Duncan, Kathy Johnson, David R. Rupert,** and **Judy Trimble** for empowering themselves and producing the manager's handbook *Employee Development—Focus on the Future*; **Shih-Jung Chang, R. Dowe Dabbs, James D. Freels, Peter C. Hambaugh III,** and **Charles T. Ramsey** for superb work on the design and fabrication of new fuel racks for the High Flux Isotope Reactor; **Manuel G. Gillispie** for exceptional dedication to photographic excellence for Energy Systems customers; **Phyllis Green** for outstanding organization of the Historically Black Colleges and Universities Workshop on the Physics of Materials and Materials Science and for working to improve workforce diversity in the Solid State Division; **Marilyn S. Hendricks** for providing exemplary support to Environment, Safety and Health in the areas of environmental protection, environmental compliance, and waste management; **H. Gerald Hodge** for distinguished service and leadership in providing quality care for indispensable research animals; **Sharron Parrish King** for accomplishments associated with managing the Solid State Division's computer system and for developing unique computer software for data acquisition and control of neutron scattering spectrometers; **Karen B. Lee** for assuming senior secretarial responsibilities for two ORNL directorates and organizing the offices to allow for overhead reduction while providing extraordinary support; **Kenneth E. Long** and **Carlie E. Miles** for outstanding efforts and exhibition of team spirit during the Oak Ridge Research Reactor pipe bypass project; **Susan R. C. Michaud** and **Randall B. Ogle** for reducing the Metals and Ceramics Division's hazardous waste by 90% by applying Total Quality Management and sound business decision-making principles; **Shirley North** for continued and extraordinary effort in the administration of the Industrial Energy Efficiency Materials Program for the Metals and Ceramics Division; **Donna L. Slagle** for exemplary financial management and contributions to the overall operation of the Metals and Ceramics Division; **Fred Smith** for superior performance in organizing and implementing the Environmental Safety and Health and quality functions in the Chemical and Analytical Sciences Division; **Carol E. Stewart** for excellent leadership and dedication in providing administrative support to the Chemical Technology Division; **Christine A. Valentine** for outstanding innovation and initiative in meeting the Energy Secretary's goal of cutting CRADA approval time by more than one-half; and **Mark C. Vance** for developing and implementing an effective quality assurance program for ORNL's Metals and Ceramics Division, a large and complex research and development organization.

Management Achievement Awards for management contributions to the activities of Energy Systems by ORNL employees went to **Jerry L. Hammontree** for successfully directing the Plant and Equipment Division using cost-effective, customer-oriented techniques; and **Michael A. Karnitz** for developing a $50 million lead role for ORNL in the Materials/Manufacturing for the Advanced Turbine Systems Program.

Technical Achievement Awards for excellence of employee contributions of a technical nature to the activities of Energy Systems went to **Lawrence F.**

Allard and **Ted Nolan** for significant accomplishments in making ORNL the nation's leading laboratory in electron holography for materials research; **Don Bible** and **Robert J. Lauf** for developing the Variable Frequency Microwave Furnace and successfully transferring the technology to industry; **John E. Bigelow** for 29 years of excellent coordination and leadership of the national program for transuranium element isotope production; **Lynn A. Boatner** and **Brian C. Sales** for the discovery and development of two new families of high-durability glasses for glass-to-metal seal and optical applications; **Katherine T. Cain** for helping to develop more than 300 translocation stocks that are providing the basis for cloning genes of significance to human health; **Harold Davis** for significant contributions to the theory and application of low-energy electron diffraction for determining the atomic structure of the surface and near-surface region; **Walderico M. Generoso** for mechanistic and imaginative approaches to research on chromosome aberrations and developmental effects that have resulted in numerous exciting discoveries; **Guy D. Griffin** and **Isidor Sauers** for sustained performance in the study of the physical, chemical, and biological properties of gas dielectrics; **Gerald R. Hadder** for developing an innovative and practical method for calculating cost-effective NO_x emission reduction standards; **William Hamilton** and **John B. Hayter** for small-angle neutron measurements of shear-induced hexagonal ordering observed in viscoelastic fluid flow past a surface; **Fred C. Hartman** and **Mark Harpel** for seminal studies of the structure-function relationships of D-ribulose-1-5, bisphosphate carboxylase/oxygenase, the life-giving enzyme; **Steven Paul Hirshman** and **Deok Kyo Lee** for a paper exhibiting a remarkable combination of theoretical elan and thoughtful focus on the question of using plasma theory to make practical contributions to the understanding of plasma physics experiments; **Michael Huston** for the first demonstrated linkage between global patterns of biodiversity and global patterns of economic development; **Philip M. Jardine** for sustained integration of field- and laboratory-scale studies with theoretical concepts to advance the understanding of nutrient cycling and contaminant mobility in unsaturated, heterogeneous soil systems; **John K. Jordan** for effectively designing and developing software and using it as a significant contribution to project successes; **Milind N. Kunchur, David Christen,** and **Charles E. Klabunde** for experimental research demonstrating the fundamental balance between the kinetic energy of an electric current and the condensation of a high-temperature superconductor; **Jih-Sheng Lai** for sustained, exemplary performance and substantial contributions toward establishing ORNL's power electronics program; **Edward A. Lazarus** for pioneering work in testing the limits of fusion plasmas; **Rich Leggett**, for a paper providing new insight into the movement and effects of lead in humans of all ages; **Douglas H. Lowndes** for discovery of a pulsed-laser method for growth of compound semiconductor thin-films and heterostructures with doping and continuously variable composition; **Chris Luck** for significant contributions to the successful development of thin-film rechargeable lithium batteries; **Rodney McKee, Lynn A. Boatner, Gerald E. Jellison Jr.,** and **Eliot D. Specht** for a paper that brings forward an entirely new and fundamental approach to the growth of a whole class of thin-film oxides; **April D. McMillan** for sustained, creative contributions supporting microwave processing and electronic materials development and for dedicated efforts in transferring the technologies to industry; **David H. Smith** for sustained contributions to progress in analytical inorganic mass spectrometry; **Audrey Stevens** for the discovery of enzymes involved in messenger RNA turnover and elucidation of their roles in regulating cell growth; **Jonathan Woodward** for a paper describing a novel, energy-saving, and environmentally friendly method for recycling waste paper with significant cost savings and implications for the pulp and paper industry; and **Thomas Zacharia** for outstanding advances in applying massively parallel computing to the modeling of material processing and behavior.

Community Service Awards for outstanding and noteworthy performance by Energy Systems employees engaged in voluntary activities that provide significant benefit to the community went to **Diana Gail Cooper** for notable contributions to the community and individuals of Anderson County by providing guidance, training, and leadership to the young, enabling them to become better citizens; **Sandra Guinn** for recognition of two decades of dedicated service at the Recording for the Blind for visually handicapped and dyslexic students; and **Thomas H. Row** for outstanding contributions of time and talent to Habitat for Humanity, United Way, and other worthwhile institutions to improve the quality of life for many people in the community.

Attracting Engineering School Gems

Two ORNL divisions are participating in a national program for workforce diversity that encourages some of the nation's most promising science and engineering students to continue in the field. Their participation provides a way for ORNL to attract cream-of-the-crop students in engineering schools to come to work at the Laboratory. The program is appropriately called GEM, for graduate education for minorities, and it has already resulted in the employment of two promising researchers in the Engineering Technology Division (ETD).

ETD began its participation in the National Consortium for Graduate Degrees for Minorities in Engineering and Science, Inc., in 1989. The result so far is two researchers on the payroll: Nathan Wood, who works in ETD's Engineering Analysis Section, and Johney Green, who works in the Power Systems Section. This year, the Research Reactors Division (RRD) has joined ETD in the program.

GEM's stated purpose is to increase annually the number of ethnic minority students who earn M.S. and Ph.D. degrees in science and engineering. The process of bringing the GEM fellows to ORNL has the drama of a professional sports draft: Getting the GEM fellows you want involves deciding on the students you want from a large pool of candidates, a lottery to determine your turn in the selection rounds, "drafting" the people you want, and "signing the contract," or having the student agree to come for a summer's employment. The last part is usually the easiest. According to Bill Craddick, who manages ETD's GEM Program, the summer internships represent an excellent opportunity for the students.

"The summer experience will be broadening and educational for them," he says. "We hope they become interested in working for us. We'll have an inside track in getting these top quality engineers as employees. Personnel people at other companies and labs say that GEM is easily their most successful program for attracting top quality minority people. With GEM, they have to make the grade, and you can hand pick them."

To be sure, GEM is not a "gimme" program. Qualifying as a GEM fellow is tough. The list of participating colleges and universities includes some of the most demanding schools in the nation. The applicant must demonstrate as an undergraduate an ability to pursue a master's degree successfully or as a graduate student the ability to pursue a Ph.D. degree as the case may be. GEM has programs for both M.S. and Ph.D. fellowships. Required are a high grade-point average and steady progress toward the degree. The students do summer internships of about 12 weeks and may return for up to three summer terms.

Participating industries and labs, such as ETD and RRD, pay $30,000 per year for the right to select two students who are about to receive their B.S. degrees. The money goes into a pool that pays for tuition, fees, and a living stipend for the GEM students. Applicants submit resumes, which are collected by GEM staff, who confirm and proofread them. (The consortium staff even recalculates GPAs from transcripts.) Then the judgment is made on whether the student qualifies.

According to Craddick, the lottery is an interesting part of the process. "We sit around tables and pick numbers that represent our drafting position. About 80 companies are represented, including almost every major technological firm or laboratory that you've ever heard of. There are two rounds. Once everyone has a number, the person with the lowest number announces which student he or she has selected. That student is now a GEM fellow who must agree to work at least one summer with the company that drafted them. There is no obligation to accept employment after they leave school, however."

RRD's Larry Proctor went to that division's first lottery with little expectation of getting its top two picks. He came back with both. But what if somebody grabs your number one pick? That's an experience that has happened to the New York Giants more than once. For the Lab, according to Craddick, it shouldn't be a problem. "We've prioritized a list of choices ahead of time. It's a good quality pool."

GEM fellows on the ETD and RRD payrolls for the summer of 1995 came from a variety of places and schools. Sharon Rogers, an RRD intern from

The program has already resulted in employment of two promising researchers at ORNL.

Through GEM, ORNL gets high-quality work during summers at student intern rates.

Summitt, Mississippi, left a high-paying job to return to Duke University to pursue a master's degree. Her GEM companion in RRD is another Mississippi native, Charles Winfrey, who hails from the town of Sunflower. Charles will complete his senior year at Jackson State University this year.

ETD's interns include Vicente Reynal, from Humacao, Puerto Rico, a graduate of Georgia Tech who has been accepted into the Massachusetts Institute of Technology's graduate program, and North Carolina A&T graduates Carolyn Baker, of Montclair, New Jersey, and Cicely Brown, of Suffolk, Virginia. The two women will both pursue master's degrees at the University of Illinois. Reynal spent much of his summer designing a plant layout for a silicon rubber manufacturing plant that will supply a critical raw material for an ORNL-developed technology.

Students participating in the GEM program who worked at ORNL in the summer of 1995 pose with former GEM students (back row, from left) Johney Green and Nathan Wood, who are now researchers in the Engineering Technology Division. The students are (from left) Vicente Reynal, Charles Winfrey, Carolyn Baker, Cicely Brown, and Sharon Rogers.

According to the ETD researchers who landed jobs at ORNL after their GEM fellowships, the current fellows' experiences at ORNL should be rewarding, both to the students and the Lab.

"When I was an intern, other researchers helped see to it that I learned about several areas of ORNL," Nathan Wood says. "This was an important experience in a multidisciplinary laboratory."

Johney Green, hired after he received his master's degree from Memphis State University, plans to work on a Ph.D. degree at Georgia Tech. "ORNL and Georgia Tech both have worked with me so that I can work toward my Ph.D. while working here," he says. "They have been very supportive."

ETD, which has participated in this program for 7 years, is happy with the results. "The division has found and hired people we are happy to have regardless of minority status," Craddick says. "This program promotes the positive image of our division. We've received calls and letters from students asking us to draft them because of recommendations from other GEM fellows."

On top of that, Craddick notes, because the GEM fellows are engineers who have B.S degrees, the division gets high-quality work during the summers at student intern rates. He expects other divisions, like RRD, to join this program because of its successful track record.

In fact, another division has. After Craddick related the success of the GEM program at an ORNL diversity workshop, ORNL's Metals and Ceramics Division decided to participate in the program's Ph.D. science component.
The main benefit of the program, Craddick says, goes to the student. The GEM program has enabled ORNL to seek out the best while providing students who have desire and ability with the means to achieve their potential.

"When people are confronted with prejudice or other obstacles, they can either use it as an excuse or be more determined to succeed," Craddick says. "Being minorities, GEM fellows have faced prejudice, and often had to overcome an economically disadvantaged background as well. But they've proven that they will not let difficulties prevent them from succeeding. That's the kind of work ethic and determination every employer wants to have in all its employees, and it's especially valuable when you're trying to find people to conduct research to find ways to overcome technological barriers."—*Bill Cabage*

Laser Technology Detects Damage in Aircraft

Aircraft are frequently struck by lightning in flight or damaged in service by extreme heat exposure. How can potential structural damage from such incidents be detected?

ORNL researchers have developed a method of imaging heat-induced damage in epoxy-resin composites. These fiber-reinforced plastics, called polymer matrix composites, are used in high-performance aircraft because they can be easily fabricated into parts of high strength and low weight. The only problem is that they may degrade when exposed to elevated temperatures from sources such as lightning, misdirected jet exhaust, and burning of spilled fuel.

Now, for the first time, early signs of thermal damage in advanced aircraft materials can be pinpointed quickly using ORNL's Composites Damage Imager (CDI). This system consists of a video camera, laser, computer, and special optics.

"The system can quickly and easily detect and display thermal damage to polymer matrix composites before measurable physical defects appear," says Eric A. Wachter, a scientist in ORNL's Health Sciences Research Division. "It offers a fast, flexible, accurate, and easy-to-use means for imaging damage to aircraft wings, flaps, and doors.

"These composites," Wachter explains, "can appear undamaged to the naked eye and even under a microscope. Yet, invisible thermal damage may have caused a composite material to lose more than half of its strength."

Tests show that CDI can image critical thermal damage in composites that cannot be detected by traditional nondestructive evaluation techniques, such as ultrasonic and X-ray imaging.

When laser light is shone on an undamaged region of a composite, the resin emits light in a specific pattern of intensities and wavelengths. The pattern of this laser-induced fluorescence changes in a recognizable way when the laser light illuminates a damaged region of the composite. A camera that detects these "spectral shifts" can be used to image damaged areas.

"The fluorescence from a suspect region of a composite can be imaged instantly," Wachter says. "The high-resolution image is automatically recorded using a video camera containing a charge-coupled device and special optical filters. The device enables the production of a false-color image that highlights the damaged areas of the material."

One other recently developed method—the Diffuse Reflectance Infrared Fourier Transform System (DRIFT)—can detect thermal damage in composites. However, the CDI technique provides a quicker response cycle.

The technology was developed to support work being conducted by the Oak Ridge Centers for Manufacturing Technology for the U.S. Air Force and Navy to detect heat-damaged composites in aircraft.

—*Carolyn Krause*

Early signs of thermal damage in advanced aircraft materials can be pinpointed quickly using ORNL's Composites Damage Imager.

Eric Wachter (right) and Walt Fisher show the composite damage imager they developed for imaging thermal damage in structural components of aircraft.

ORNL Uses Bacteria To Turn Coal Pollutant into a Product

ORNL researchers have shown that certain bacteria can convert sulfur dioxide into hydrogen sulfide, which can be converted to elemental sulfur.

ORNL researchers have found a way to turn a pollutant into a useful product. The pollutant is sulfur dioxide from coal-fired steam power plants (which helps cause acid rain), and the product is elemental sulfur. Their biological process could save energy while reducing pollution and waste.

Eric Kaufman, a researcher at the Bioprocessing Research and Development Center in ORNL's Chemical Technology Division, and P. T. Selvaraj, a postdoctoral scientist at the center, are using bacteria to convert sulfur dioxide and other sulfur oxide products into hydrogen sulfide, which they then convert chemically or biologically into elemental sulfur. They have also found that these bacteria can live off sewage, making the process economical.

Sulfur, a natural component of coal that is released to the air as sulfur dioxide when coal is burned, is the largest-selling element in the United States. It is used to make the largest-selling commodity chemical—sulfuric acid, which is essential to the manufacture of plastics, fertilizers, and other products.

"A 500-megawatt coal-fired power plant that burns coal that is 3.5% sulfur with no sulfur dioxide control," Kaufman says, "has the potential of releasing up to 360 metric tons of sulfuric acid per day." Sulfuric acid, a component of acid rain, is formed in the atmosphere when sulfur dioxide reacts with moisture there.

American utilities must comply with increasingly stringent requirements to reduce emissions of sulfur dioxide to the atmosphere. These requirements are being phased in under the Clean Air Act Amendments of 1990 to protect the public from this air pollutant, which can cause potentially fatal respiratory illnesses, and to reduce acid precipitation, which can slow the growth of forests and fish populations.

Utilities can meet these requirements in several ways. They can burn lower sulfur coal or they can treat flue gas containing sulfur dioxide as it is produced at coal power plants. The treatment is called flue gas desulfurization (FGD) because it removes sulfur from the gas.

In the more commonly used treatment, called limestone-forced oxidation, the sulfur dioxide in the gas is passed through a slurry of water and limestone (calcium carbonate). The reaction yields the product calcium sulfate, commonly known as gypsum.

Although this FGD waste gypsum is used for wallboard in Japan, in the United States it cannot compete economically with mined gypsum. While 1% is used for cement and building materials in this country, most gypsum—some 20 million tons a year—is buried or stacked in landfills.

A second, emerging flue gas treatment is the use of regenerable sorbents. Here, sulfur dioxide is absorbed onto a catalyst and then is freed to generate a concentrated sulfur dioxide stream. This stream is run through a hydrotreatment process, which requires methane and water to add hydrogen to sulfur dioxide. Hydrogen sulfide formed in the hydrotreating process is then combined with additional sulfur dioxide in a Claus plant to produce elemental sulfur.

To conduct their bioprocessing experiments, Kaufman and Selvaraj introduced into a vertical glass cylinder, or bioreactor, two types of bacteria—sulfate-reducing bacteria (SRBs), which cannot tolerate oxygen, and heterotrophs, which remove oxygen to help the SRBs survive. The bacteria are fed a sewage digest that provides the bacteria with carbon, their main food source.

"Use of pretreated sewage as the source of carbon makes this process economical," Kaufman says. "Without this approach, we'd have to buy expensive organic acids to serve as the food source for the bacteria."

In the bioreactor, gelatin-like beads containing SRBs are suspended in sewage media through which sulfur dioxide flows. The SRBs convert the sulfur dioxide into hydrogen sulfide.

"We got the idea that SRBs can also break down the sulfate in calcium sulfate, which is gypsum," Kaufman says. "Gypsum is accumulating at many coal-fired steam plants as an end product of flue gas desulfurization. By dissolving the gypsum in water or sewage media, we can make a slurry that can be passed through

P. T. Selvaraj, a postdoctoral scientist with the Bioprocessing Research and Development Center at ORNL, adjusts controls on a bioreactor. The glass vessel contains bacteria in beads suspended in sewage media. Sulfur dioxide, a coal power plant pollutant, is passed through the bioreactor, and the bacteria convert the pollutant to hydrogen sulfide for subsequent conversion to sulfur, a useful product.

our bioreactor, where it is converted to hydrogen sulfide."

To reduce the amount of gypsum accumulating at coal plants, Kaufman and Selvaraj propose a process to reclaim sulfur from calcium sulfate and regenerate the limestone (calcium carbonate) used to produce gypsum from sulfur dioxide. Their research suggests this scheme could reduce carbon dioxide emissions from coal-fired power plants.

"While the sulfur from the waste gypsum is reclaimed as elemental sulfur, calcium can be precipitated to form the original calcium carbonate using waste carbon dioxide from the coal plant," Kaufman says. "Thus, by making the process more efficient, we can at the same time reduce the coal plant's emissions of carbon dioxide, which can increase the greenhouse effect and possibly alter the climate."

Selvaraj and Kaufman are also developing biological and chemical processes for conversion of hydrogen sulfide into elemental sulfur. In one such process, sulfide is oxidized by ferric iron to form sulfur and ferrous iron. The ferrous iron is then reoxidized by bacteria so that it may be reused with no chemical wastes.

The hydrogen sulfide also could be passed through a Claus plant. But a bioreactor might be preferable because it would use less energy.

The researchers also conducted experiments that confirmed that an electrical current could be used to separate sulfur from oxygen in sulfur dioxide. However, Kaufman says, electrochemical reduction of sulfur dioxide is more expensive than the biological approach because it uses considerable electricity.

—Carolyn Krause

This scheme could reduce carbon dioxide emissions from coal-fired power plants.

Ceramic Needles May Prolong Engine Life

Automobile engine cylinders could last much longer if they were formed from composites of metals and ceramics. But the ceramic used to make the most wear-resistant metal-ceramic or ceramic-ceramic composite must meet two requirements. It must be one of the hardest known ceramics, such as tungsten carbide, which is used for tough coatings and cutting tools. And it must have a desired shape, such as that of a needle, so that it can reinforce the metal to make a very hard composite, just as straw was once used to reinforce bricks and clay for ancient homes.

This work is valuable because it shows for the first time that needles of tungsten carbide can be made from needles of another starting material.

Carlos Bamberger, an ORNL chemist, has discovered a chemical method for producing tungsten carbide needles from needle-shaped crystals of sodium tungsten bronze, an inexpensive material. The chemical reaction employed is a "pseudomorphic reaction" in which the final product has the same shape as the material initially used in the reaction.

"The performance of a material is often strongly dependent on its shape, or morphology," Bamberger says. "For example, whiskers of silicon carbide, a very hard and durable material, have been shown to strongly reinforce other ceramics.

"Because the morphology of a material during synthesis cannot be predicted, this work is valuable because it shows for the first time that needles of tungsten carbide can be made from needles of another starting material."

Bamberger, a senior staff member of ORNL's Chemical and Analytical Sciences Division, believes that properly shaped tungsten carbide could be used to form ceramic composites and ceramic-metal composites that have industrial use.

To produce a material that is about 75 to 80% tungsten carbide and about 20 to 25% tungsten metal, Bamberger reacted solid crystals of sodium tungsten bronze with various hydrocarbon gases at high temperatures. The proportions of tungsten carbide and tungsten metal, he found, could be altered by varying the temperature, flow rate, and composition of the hydrocarbon gas.

This micrograph shows tungsten carbide–tungsten needles produced in the chemistry laboratory of Carlos Bamberger from needle-shaped crystals of sodium tungsten bronze. These needles could be used to make ceramic-metal composites for engines.

"This experiment," Bamberger concludes, "showed that, by a simple reaction with a common gas, an inexpensive material could be converted into an industrial product of potential high value."

—Carolyn Krause

ORNL Method May Detect Hidden Marijuana Gardens

Many cannabis gardens, from which the illegal drug marijuana is obtained, can be spotted by inspectors on the ground or in airplanes. But some cannabis gardens escape optical detection because they are planted beneath a dense canopy of foliage in such areas as national forests.

Scientists at ORNL may have a solution to this problem. In work sponsored by DOE and the U.S. Forestry Service, they have developed an advanced method for detecting hidden cannabis gardens. Their method "sniffs" trace vapors from the pot smoker's plant.

The detection method uses a portable ion-trap mass spectrometer and personal computer, called a Multi-Threat Analyzer (MTA). In a field test in the summer of 1994 at a legal cannabis garden grown by the U.S. government for evaluation of detection technologies, ORNL researchers demonstrated that the MTA can detect and analyze trace levels of airborne organic vapors from mature cannabis plants under normal growing conditions.

"The field test was very successful," says Marcus Wise, an MTA developer and scientist in ORNL's Chemical and Analytical Sciences Division. "The MTA detected a wide range of volatile organic compounds of various molecular weights.

"It appears that the higher-molecular-weight compounds—hydrocarbons called terpenes that are found in oils, resins, and balsams—may be unique enough to the cannabis plant to be used as a signature for detection."

In the test, Wise says, the MTA was operated in the field to determine if it could detect organic vapors from the cannabis plant in real time. Also, vapor samples were collected on sorbent tubes and later analyzed in the laboratory.

The data collected and displayed as spectra by the MTA indicated that the organic compounds in the vapors were related to terpene. These findings at the garden site were confirmed in the laboratory by gas chromatography and mass spectrometry of the sorbent tube samples.

"When we operated the MTA in a conventional mode at the garden," Wise says, "we found we could detect several molecules of organic compounds for every billion molecules of air in our samples. Newer ion traps, which can be operated in an advanced mode, will allow us to detect organic compounds at levels lower than one part per billion in air as they are emitted from cannabis plants."

"Work is scheduled to continue on this project," Wise says, "The plan is to optimize MTA operating conditions for maximum sensitivity and to survey other vegetation for the presence of the target terpenes."

In the late 1980s, Wise, Michelle Buchanan, and Mike Guerin, then of ORNL's Analytical Chemistry Division, developed new sample-handling equipment and computer software to enable an ion-trap mass spectrometer to sample and monitor air directly. Today this system can detect and measure trace levels of organic compounds in air, water, soil, and body fluid samples within minutes.

Participants in the marijuana research include Wise from the Instrumentation Group; Jan Ma from the Analytical Methods Group; and Rob Smith from the Environmental Monitoring Group, all in ORNL's Chemical and Analytical Sciences Division.

—Carolyn Krause

ORNL scientists have developed an advanced method for detecting hidden cannabis gardens.

Modified Iron Filings Remove All Chlorine from Groundwater

Iron filings—the materials students sprinkle on paper above a magnet to see signs of a magnetic field—can also be used to clean up groundwater

They have shown that iron filings sprinkled with palladium rapidly remove all ... chlorine, in ... groundwater.

contaminated with organic compounds containing chlorine. However, researchers at ORNL and the University of Arizona have dramatically improved this process. They have shown that iron filings sprinkled with palladium rapidly remove all, not just part of the chlorine, in the organic compounds, making the groundwater environmentally acceptable.

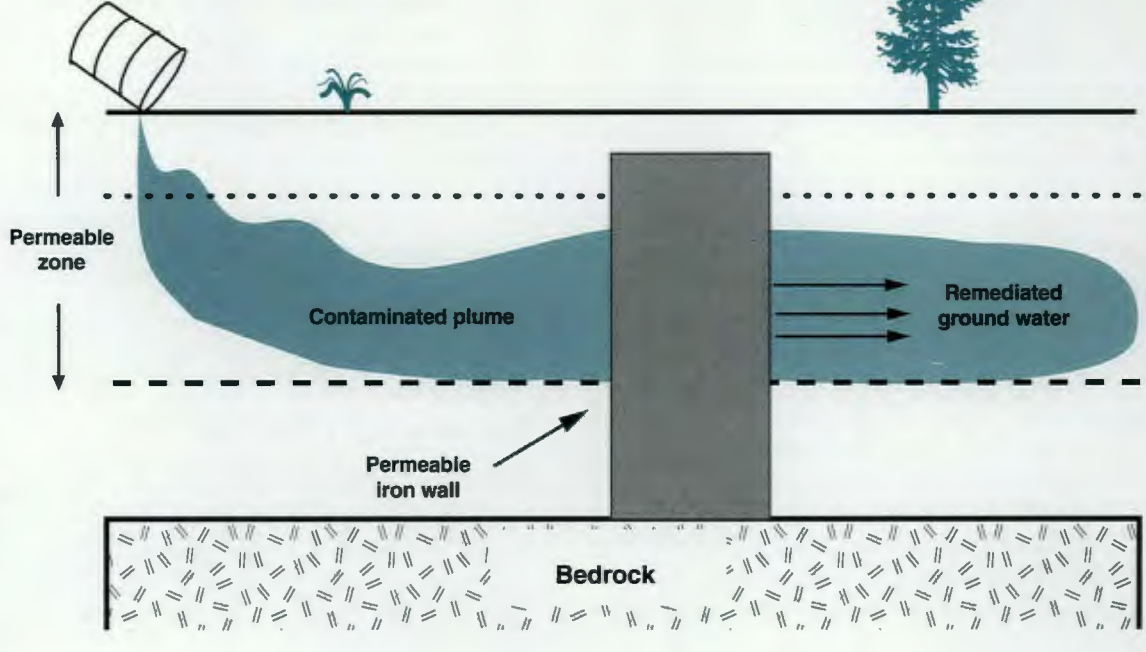
Nic Korte and Liyuan Liang, both group leaders in the Earth and Engineering Sciences Section of ORNL's Environmental Sciences Division, and their associates have studied the effectiveness of iron filings in removing chlorine from organic solvents in contaminated groundwater. They evaluated whether iron filings could be incorporated in a porous wall placed in front of an advancing contaminant plume in groundwater to treat water at two DOE sites. The wall technology was initially developed and patented by a group at the University of Waterloo in Canada.

Groundwater at DOE's uranium enrichment facilities is contaminated with trichloroethylene (TCE), a chlorine-containing organic solvent once commonly used to remove dirt and grease from metals. Because the toxic material is present in concentrations exceeding Environmental Protection Agency (EPA) limits, DOE's Office of Environmental Management is interested in the possibility of using iron wall technology for in situ treatment of groundwater. Korte and Liang were asked to evaluate the effectiveness of this technology for use at two enrichment facilities, the Paducah, Kentucky, and Portsmouth, Ohio, gaseous diffusion plants.

In the ORNL studies, it was found that dechlorination of TCE occurs on the surface of the iron filings. Also, the researchers observed that the by-products of the reaction include partially dechlorinated compounds, such as dichloroethene and vinyl chloride, and completely dechlorinated hydrocarbons, such as ethene and ethane, which are not of a great concern at trace levels.

"We found that in a batch reactor, about 20% of the by-products contain chlorine, indicating that complete dechlorination had not occurred with elemental iron alone," Liang says. "One of these byproducts—about 8% of the total—is vinyl chloride, which must be kept at trace levels —1 part per billion or below—to meet EPA or state regulations."

To achieve complete dechlorination, rather than partial ORNL and University of Arizona researchers



A permeable wall of iron filings, serving as an in situ reactive barrier in groundwater, removes chlorine from a contaminated groundwater plume. An iron-palladium preparation was found to be even more effective in achieving total dechlorination.

jointly designed and tested an iron-based material containing a trace amount of palladium. The presence of the palladium, a catalyst, increases the rate of dechlorination 10 to 100 times and minimizes the production of undesirable vinyl chloride (reducing it from 8% to less than 1% of total by products).

"Because of the effectiveness of this bimetallic system," Liang says, "we can achieve total dechlorination in less time."

Liang and Korte say that palladized iron also shows promise for separating organic solvents from radionuclides in mixed waste and in degrading dichloromethane, a hazardous product of the breakdown of carbon tetrachloride. In addition, iron is more efficient than a conventionally used synthetic resin for removing radioactive technetium from water; technetium is a waste product of some nuclear processes.

To determine the exact proportions of by-products formed in the reaction between TCE and iron, the researchers used zero-headspace extractors and a purge-and-trap concentrator with a gas chromatograph (GC) in the laboratory. The extractor is a closed cylinder that contains the sample solution but excludes air space (head space), preventing the organic compounds from volatilizing from the water. Lack of control in keeping organic compounds from escaping from water could cause inaccuracies in the measurements of the amounts and proportions of TCE by-products in the treated water.

A water sample for GC analysis is obtained from the top of the apparatus by forcing the internal piston up, using pressurized gas introduced at the bottom. "Because the batch reactor is a closed system," Liang says, "all by-products and their concentrations in water during treatment can be precisely measured and a good mass balance can be achieved."

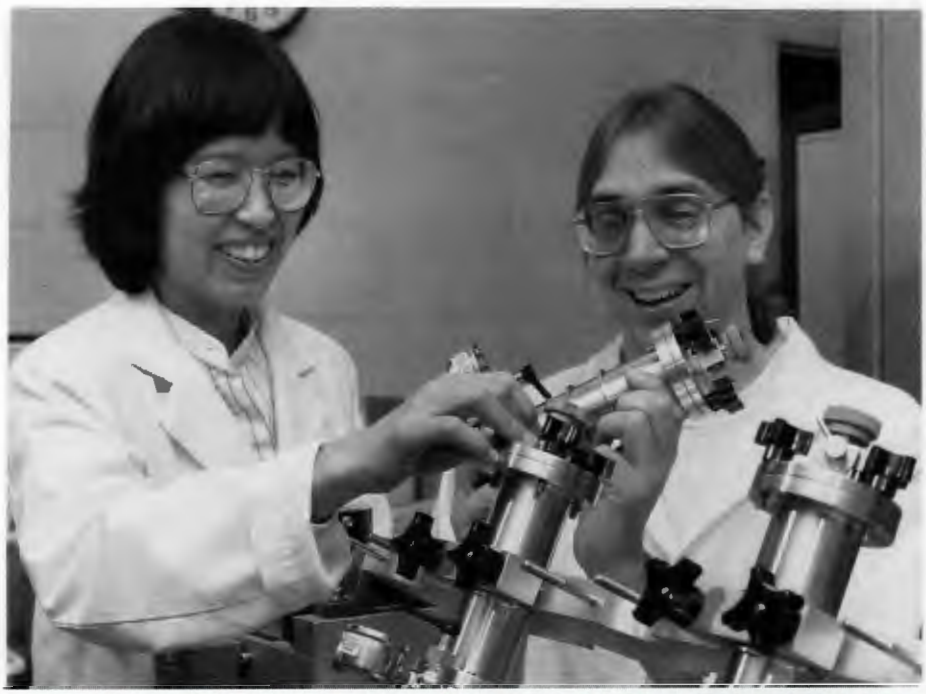
The researchers also studied the rates of the dechlorination reactions using fine iron filings and iron filings coated with palladium. "One flow-through column study," Liang said, "showed that removal of half of the TCE in a pure iron system occurred in about 10 minutes. With the addition of the palladium in the amount of about 0.05% of the iron, the removal time is reduced to seconds."

The detailed pathways and mechanisms for the dechlorination reactions involving the metals are still unknown. In the dechlorination reaction, iron atoms donate electrons, breaking the bonds between the chlorine atoms and the carbon atoms in the organic compounds. Most chlorine is released as a chloride ion or combines with ferrous iron to precipitate out as green rust.

The research was sponsored by DOE's Office of Environmental Management. Korte and Liang's collaborators in the research include John Goodlaxson and Abinash Agrawal, both of ORNL's Environmental Sciences Division; Rosy Muftikian, Carina Grittini, and Quintus Fernando, all of the University of Arizona in Tucson; and Jay Clausen of DOE's Paducah Gaseous Diffusion Plant.

—Carolyn Krause

Palladized iron also shows promise for separating organic solvents from radionuclides in mixed waste.



Liyuan Liang and John Goodlaxson adjust the zero-headspace extractors for studies of the effectiveness of iron and palladium in removing chlorine from organic compounds found in contaminated groundwater.

Electromagnetic Field Bioeffects Laboratory Opens at ORNL

Concerns about EMF health risks are costing U.S. society an estimated $1 billion a year.

Some people have become edgy about living on the edge—of power line corridors. The reason: Population studies in Colorado and Sweden have suggested a link between households near power lines, which generate extremely low-frequency electromagnetic fields (EMFs), and an unusual number of children suffering from leukemia and brain tumors.

EMFs make the public nervous also because they are present everywhere. They are generated by home appliances such as microwave ovens, personal computers, hair dryers, and electric blankets. The public is not reassured by the fact that scientists disagree on whether EMFs are an invisible threat to health.

Concerns about EMF health risks are costing U.S. society an estimated $1 billion a year in lawsuits, rerouting power lines or locating them underground, and redesigning products such as computer monitors and electric blankets to minimize EMF exposure. For this reason, the Department of Energy and the Electric Power Research Institute, the research arm of the U.S. utility industry, have spent $68 million on studies of EMF bioeffects.

In May 1995, the American Physical Society issued a statement that its review of the scientific literature found "no consistent, significant link between cancer and power line fields." But there are still questions to be resolved because of evidence of subtle effects of EMFs on cell membranes, and ORNL physicists and biologists have been grappling with these questions for several years.

Because of insufficient evidence to link EMF bioeffects with measurable health effects, DOE has established four national facilities that will determine if previously observed biological effects of EMFs can be reproduced consistently. One such facility is now operating in Oak Ridge. On June 9, 1995, ORNL's Electromagnetic Fields Bioeffects Laboratory was dedicated.

David Reichle (left), Paul Gailey, and Guy Griffin examine ORNL's Electromagnetic Fields Bioeffects Laboratory.

In 1990 ORNL became DOE's lead national laboratory to assist in management of the national EMF program. ORNL also conducts technical workshops, assembles and distributes packets of information, and reviews results of DOE-funded research on EMF bioeffects. ORNL is responsible for ensuring the quality of research at universities and other government laboratories under the DOE program. Clay Easterly of the Health Sciences Research Division and Paul Gailey of the Energy Division both worked on a report on EMFs for the Environmental Protection Agency, focusing on epidemiological studies, risk assessment, and policy analysis. The report concluded that EMFs may cause subtle biological effects, but added that it is not yet clear that EMFs pose a health risk.

The theory that EMFs cause biological effects such as cancer is controversial for three reasons, says Gailey, a physicist.

"First, some epidemiological studies of various populations, beginning with a study in 1979, have shown a trend toward a higher incidence of cancer for people living near power lines," he notes. "But this correlation has not always been observed in studies of exposed populations.

"Second, no physical mechanism has been proposed to adequately explain reactions of biological tissue to weak electromagnetic fields in the environment. A theoretical problem is sorting out the effects of these environmental EMFs from the influence of the body's own electrical fields from nerve signals and background noise from the earth's geomagnetic field.

"Third, subtle EMF effects have been detected in cells such as changes in the flow of ions and increases in the proliferation of a line of cancer cells. But these effects have not been replicated consistently. That's why the government is supporting four EMF replication facilities."

The other three EMF bioeffects facilities are a Food and Drug Administration laboratory in Rockville, Maryland; a National Institute for Occupational Safety and Health laboratory in Cincinnati, Ohio; and DOE's Pacific Northwest Laboratory in Richland, Washington. The results of the experiments from these facilities will be used for a risk assessment to be completed by 1997 as mandated by the National Energy Policy Act of 1992. The assessment will be prepared by DOE and the National Institute of Environmental Health Sciences.

Startup funds for EMF research at ORNL came from an internal source: the Laboratory Directed Research and Development Fund. Later, DOE contributed $75,000 to purchase and install the EMF exposure system.

The facility consists of two exposure chambers, each containing a box for cell and tissue samples surrounded by a coil. When the coil is electrified, it produces an electromagnetic field. A computer operates the whole system, turning on one coil but not the other for each study. Researchers do not know which sample is exposed to the EMF until after the data are analyzed, preventing them from being biased in interpreting results. After they have analyzed the data, the computer tells them which of the two samples was exposed to EMFs.

The blind cell culture experiments at the facility are being conducted by biologist Guy Griffin of the Health Sciences Research Division; Gailey and Griffin will analyze the results. The first experiment used genetically engineered breast cells that emit light when exposed to estrogen-like compounds. The researchers searched for possible effects of EMFs on breast cells by measuring the cells' dim light emissions. The researchers will also try to replicate the results of a study that suggests that EMFs cause abnormal nerve cell growth.

Gailey says that many schools are built near power lines because land next to power corridors tends to be inexpensive. Some worried parents, he adds, take their children out of neighborhood schools near power lines and drive them farther away to a different school. "The safety risk of driving the extra distance each day is measurable," he says, "but the hypothetical health risks of EMFs are not. The decision to change schools is difficult to justify based on current scientific information."

—Carolyn Krause

ORNL became DOE's lead national laboratory to assist in management of the national EMF program.

Science and Technology Partnership Office Opens at ORNL

We have about 4000 guest researchers here annually. Our new center will make the Laboratory more accessible to them.

ORNL's new Science and Technology Partnership Office has opened. The building, located near ORNL's East Portal, houses offices of the ORNL technology transfer and user center programs. Full-time staff in the new facility total 20. Guest researchers and foreign nationals working at ORNL will also use the facility as an access point.

Louise Dunlap, director of the Office of Science and Technology Partnerships, said the new facility will bring together technology transfer functions into a central location that will enable the office to serve both its internal and external customers more efficiently.

"Both the user center and guest research programs attract large numbers of scientists to the Lab," Dunlap says. "We have about 4000 guest researchers here annually, or about 1500 FTEs (full-time equivalents). These researchers enhance our scientific staff. Our new center will make the Laboratory more accessible to them."

The Energy Research Laboratory Technology Applications Program, which is managed by Tom Rosseel through the partnership office, is a major resource for technology transfer programs at the Laboratory. In addition to cooperative research and development agreements (CRADAs), this program includes personnel exchanges, technology maturation, and technical assistance projects.

This program also provides funding and leadership for such broad efforts as the American Textile Initiative (AMTEX), a CRADA program involving the American textile industry and 10 DOE laboratories, including ORNL.

The user center program, which encompasses 11 facilities at ORNL and one at the Oak Ridge Y-12 Plant, attracts both academic and industrial users. About 300 universities and private firms have active user agreements.

The Minority and Small Business Office headed by Will Minter will also be located in the new facility. This group informs small and minority businesses of opportunities to work with ORNL staff and facilitates such interactions.

—Fred Strohl

Alcoholism Gene Studied in Mice at ORNL

Reaching once again into their treasure trove of genetic information and selectively bred mouse stocks, researchers in ORNL's Biology Division are now helping to uncover the genetic roots of alcoholism. Working in collaboration with a research team at the University of Colorado at Boulder, genetics researcher Dabney Johnson and her associates are investigating one of at least eight genes believed to play a role in determining whether mice develop a condition similar to human alcoholism.

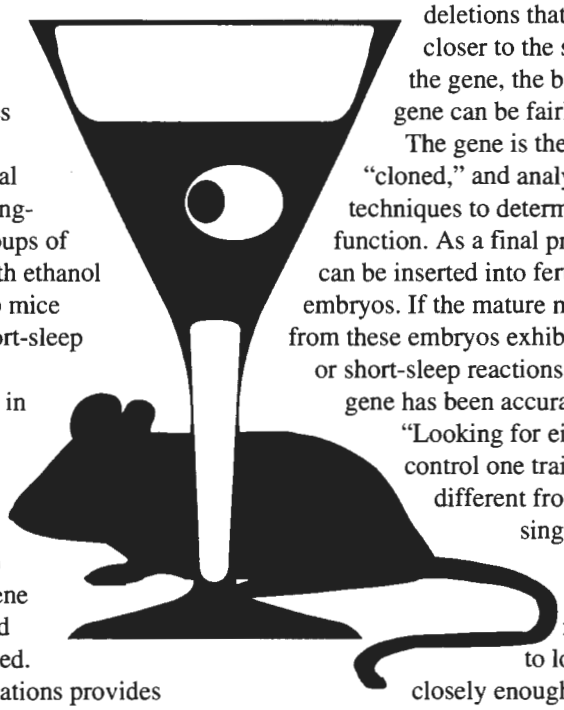
Johnson and her group were brought into the study when University of Colorado researchers found that the gene they were looking for was located in a region of a chromosome that has been extensively studied at ORNL since 1947. The ORNL studies had examined chromosomes from which small pieces had been knocked out, or "deleted," by exposure of mouse sperm to radiation.

"The gene we are looking for is located near the albino gene, a defective form of the gene that controls the amount of pigment in skin and hair," says Johnson. "Because the effect of having or not having the albino gene is obvious to the naked eye, it was one of the focal points of early genetics research at ORNL. As a result, we have mice with about 50 different deletions around the albino locus."

Traditional research into inheritance patterns concentrates on studying traits that are determined by a single gene—like extra fingers. In these situations, if one parent carries the gene for extra fingers, a dominant gene, their child has one chance in two of having the trait. If both parents carry the gene, the child's chances of having extra fingers increase to three in four. In the case of a recessive gene like the one that causes cystic

fibrosis, a child's chance of developing the disease is one in four if both parents carry the gene. If only one parent carries the gene, the child has one chance in four of becoming a carrier of the gene, but will not develop the disease.

Recently, computer-assisted analysis of genetic experiments has enabled researchers to digest the vast amounts of data necessary to study more complex traits, such as alcoholism, which are controlled by the interaction of several genes. The initial Colorado studies identified two lines of mice that differ dramatically in their physical reaction to alcohol. Known as "long-sleep" and "short-sleep," both groups of mice fall asleep when injected with ethanol (grain alcohol), but the long-sleep mice sleep 20 times as long as their short-sleep counterparts.



Unlike some of the other genes in the eight-gene group, such as the genes that control behaviors related to alcohol-water preference and alcohol withdrawal, the exact relationship of the long-sleep or short-sleep gene to an individual's tendency toward alcoholism has yet to be determined. "We can't tell which of these variations provides the good input and which provides the bad," says Johnson.

By breeding mice having selected deletions with long- and short-sleep mice, Johnson hopes to isolate the location of the gene more closely. For example, breeding a mouse with one of its sleep time control genes deleted entirely with a long-sleep mouse would result in half of the offspring being purebred long-sleep mice. On the other hand, if a long-sleep mouse were bred with a mouse having two intact sleep time control genes, then none of their offspring would exhibit the long-sleep reaction to alcohol. By breeding long-sleep or short-sleep mice with mice having deletions that come closer and closer to the suspected location of the gene, the boundaries of the gene can be fairly closely defined.

The gene is then copied, or "cloned," and analyzed by laboratory techniques to determine its structure and function. As a final proof, the cloned gene can be inserted into fertilized mouse embryos. If the mature mice that develop from these embryos exhibit the predicted long- or short-sleep reactions to alcohol, then the gene has been accurately identified.

"Looking for eight genes that control one trait isn't that much different from looking for a single gene that controls a trait," Johnson says. "It's just a matter of being able to localize the genes closely enough. Then we can use our usual tricks to go in and find them."

Such a discovery would move science one step closer to understanding the genetic bases of alcoholism in humans and help lay the foundation for research into treatments for this condition.

—Jim Pearce

Looking for eight genes that control one trait isn't that much different from looking for a single gene that controls a trait.

ORNL and SpectRx Are Developing Painless Report Card for Diabetics

This pain-free test for diabetics will measure light emissions from an illuminated eye.

If you're a diabetic, you must go through an annoying ritual every three months. When you visit your doctor, a nurse pierces you with a needle and takes your blood. The needle hurts you, and the sight of blood makes you feel ill. Then you have to wait a couple days for the test results.

The test is the "hemoglobin A1c" procedure—a diabetic's report card. It tells your doctor how well you have controlled your diabetes over the past 90 days. If the test results are bad, the doctor may put you on a more tightly controlled diet and require you to check your glucose levels daily through a painful finger stick.

Tuan Vo-Dinh and his colleagues in ORNL's Health Sciences Research Division are working with SpectRx, Inc., of Norcross, Georgia, to develop a pain-free, noninvasive hemoglobin A1c test that is fast—it provides results in seconds, not hours. This noninvasive test being developed by SpectRx measures light emissions from an illuminated eye using technology developed at ORNL.

"Our improved test should be as good as or better than the current hemoglobin A1c procedure," says Mark A. Samuels, president of SpectRx. "We believe that our system will have several advantages over the current hemoglobin A1c test. It will be noninvasive, much faster, and cheaper. It will produce no hazardous waste that is costly to dispose of, and it will eliminate exposure to blood-borne pathogens.

"There is a wealth of knowledge at ORNL that is just waiting to be developed into beneficial technology," Samuels adds. "The technology for which we have a license has the potential to improve the health care for people with diabetes."

Diabetes mellitus is a disorder that affects millions of Americans. It is caused by the inability of the body to use its food efficiently because of an insufficient amount of the hormone insulin. This secretion of the pancreas gland breaks down, or metabolizes, glucose sugar from carbohydrates. Diabetics suffer from excessive thirst, hunger, loss of weight, and various problems such as heart attacks, kidney failure, and blindness. Diabetes mellitus is the leading cause of blindness."

The hemoglobin A1c test is given to diabetics routinely to determine how well the patient is maintaining long-term blood glucose levels.

"When an individual becomes diabetic, the protein molecules of the eye change because of long-term exposure to glucose," says Jonathan Eppstein, vice president of research and development for SpectRx. "The SpectRx technology enables us to detect these subtle changes in a rapid, noninvasive manner."

Vo-Dinh and his colleagues, working with SpectRx, are developing the diabetes hemoglobin A1c instrument that uses synchronous fluorescence spectrometry, a technique developed by Vo-Dinh in 1978 at ORNL that was once used in England to identify sources of oil spills. The SpectRx instrument will include a new device being developed at ORNL that will provide a rapid, accurate profile of the molecular makeup of the eye, enabling a physician to measure the patient's long-term glucose control levels.

"With this new device," Vo-Dinh says, "it will be possible to detect subtle changes in the eye in less than a second because our device will identify many different molecules in eye tissue at about the same time."

The ORNL technology has been licensed to SpectRx, Inc., in an agreement with Lockheed Martin Energy Systems, which manages ORNL for the Department of Energy.

The SpectRx device using ORNL technology would simultaneously scan the eye with light of varying wavelengths and with a detector that picks up light emitted by the illuminated eye. Simply speaking, this approach is similar to

illuminating a person's eye with a flashlight whose light keeps changing color and observing the color changes in the eye at the same time.

If light of a particular wavelength (color) falls on molecules in the lens of the eye, some will become energized, or excited. Then they will return to their normal state by releasing their excess energy in the form of photons of light. Molecules will fluoresce when excited by light of appropriate wavelengths.

A detector combined with a light source can measure the intensity of light emitted by the eye for each wavelength of light shone into it. The intensities from scanning the eye are recorded as peaks of different heights and positions in a spectrum, which resembles a range of mountains and valleys. A computer compares known spectra for normal and diabetic eyes with the spectrum from a patient's eye, allowing long-term glucose levels to be determined.

Synchronous fluorescence spectrometry, Vo-Dinh says, is superior to conventional excitation spectrometry because scanning a target simultaneously with a light source and detector, rather than separately, produces smaller, sharper peaks. Each peak in the spectrum represents molecules of a particular type.

Thanks to recent technology, Vo-Dinh and his colleagues were able to design a device that performs synchronous fluorescence spectrometry in milliseconds rather than minutes. The heart of the device is acousto-optic tuneable filters, commercially made crystalline materials that can be "squeezed" by sound waves of a specific radiofrequency to select the desired wavelength of light to be passed through the crystal to the eye.

The light is transmitted into the crystal and to the eye by an optical fiber. Multidimensional detectors pick up light transmitted from the eye through an optical fiber. To automate operation of the instrument and to acquire and analyze the spectral data, special computer software is being developed by ORNL postdoctoral scientists Dennis Hueber and Chris Stevenson.

Working with Vo-Dinh's group in a cooperative research and development agreement, SpectRx plans to develop a compact counter-top or hand-held device that combines a low-cost light source that is safe for the eye with a detector that receives light emitted by the eye.

Thanks to recent technology, Vo-Dinh and his colleagues were able to design a device that performs spectrometry in milliseconds rather than minutes.

The diabetes hemoglobin A1c device being developed at ORNL with SpectRx is examined by, from left, Tuan Vo-Dinh of ORNL's Health Sciences Research Division; Jonathan Eppstein, vice president of research and development for SpectRx; Mark Samuels, president of SpectRx; and Dennis Hueber, a postdoctdoral scientist who works with Vo-Dinh.

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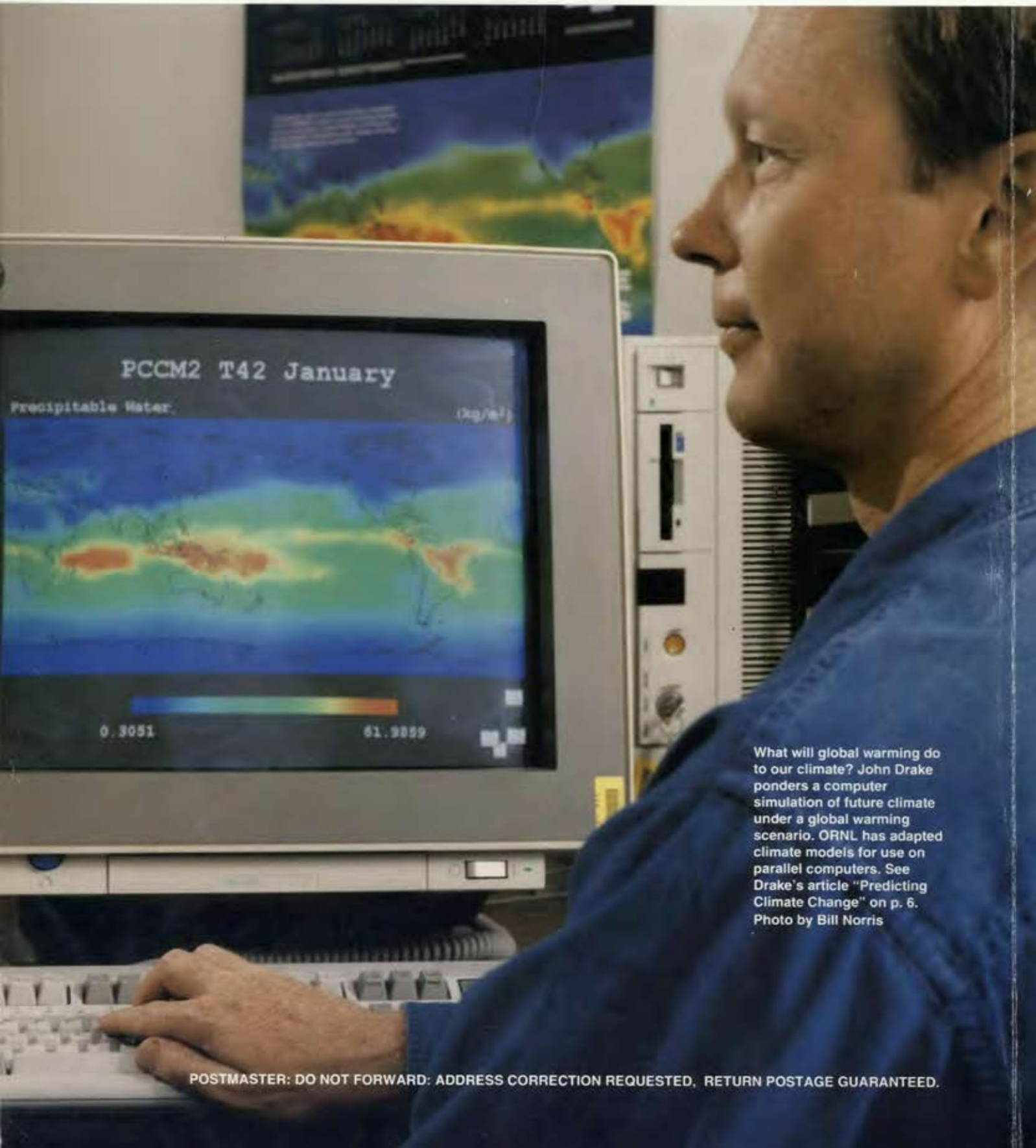

What will global warming do to our climate? John Drake ponders a computer simulation of future climate under a global warming scenario. ORNL has adapted climate models for use on parallel computers. See Drake's article "Predicting Climate Change" on p. 6. Photo by Bill Norris