Oak Ridge National Laboratory

REVIEW

• MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY •

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A Matter °f Degrees

THE FUTURE of CLIMATE CHANGE RESEARCH

Slowing CO_2 Emissions

Adapting to Climate Change Impacts

Oak Ridge National Laboratory

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on the cover

A soybean field.

A MATTER OF DEGREES

I remember as if it were yesterday, lying in my dorm room, unable to sleep. A college freshman, I had just finished reading *The Population Bomb*, a best-selling book filled with scientific and anecdotal data that predicted by the end of the 20th century an inevitable human disaster created by the world's overpopulation. More than three decades later, technologies unimagined when the book was written have more than doubled world food production. Contrary to the book's predictions, countries such as India are actually net exporters of food. While regional famine certainly exists and the issue of providing an expanding world population with adequate food supplies remains a serious challenge, few observers anticipate, at least any time soon, the kind of apocalypse envisioned in *The Population Bomb*.

When we experience the decibel level associated with climate change, we cannot help but wonder if we are witnessing a contemporary variation of a similar discussion or an imminent scientific issue of global magnitude. Multiple lines of evidence have convinced a large majority of the scientific community that a steady stream of greenhouse gases since the Industrial Revolution has produced a pattern of sustained global warming. This consensus has not, however, translated into agreement about the precise impact of global warming or how society should respond. Some call for immediate and dramatic actions at both the personal and political levels to mitigate climate change. Others are more cautious, pointing out that an array of new technologies may soon expand options for both mitigation and adaptation.

Against this backdrop, Oak Ridge National Laboratory is taking a leading role in helping seek answers to a host of unresolved questions in the climate debate. We undertake this challenge mindful of the need to produce scientific data untainted by any ideological or political agenda. Our goal is simply to provide a neutral scientific context in which policymakers can reach an informed decision.

This issue of the *ORNL Review* is dedicated to the multidisciplinary suite of climate change research taking place in Oak Ridge. One group of researchers is focused upon determining the causes and impacts of climate change. A second is looking at ways, both large and small, by which we can potentially mitigate climate change. The third, and perhaps most unique group assumes the inevitability of climate change and thus is examining how humans can best adapt to a warmer future.

Together, ORNL's climate research addresses many of the questions contained in a debate that is certain to continue for the foreseeable future. As has been the case throughout the last 60 years, the Laboratory is dedicated to marshaling our resources to find solutions to one of the biggest scientific challenges of our time. How one views this research, and the extent to which it is accepted by the public and the scientific community, may ultimately be, quite literally, a matter of degrees.

Billy Stair

Billy Stair
Director, Communications and
External Relations Directorate

"Most scientists viewing the accelerated burning of fossil fuels now agree that excess CO_2 will warm the earth's surface temperature significantly… Clearly it is necessary to foresee more accurately the consequences of the continued use of fossil fuels…"
—The Global Carbon Dioxide Problem, C.F. Baes *et al*, August, 1976

THE MOST COM OF SUBJECTS

During the 30 years since three Oak Ridge National Laboratory scientists helped pen this paper examining evidence of climate change, many of the same questions remain regarding how the unseen remnants of the world's growing dependence on fossil fuels have affected and may continue to affect the planet for generations to come. Humans are, in fact, performing an inadvertent experiment on Earth that is increasing the concentration of CO_2 in the atmosphere well beyond historic levels. The result is a growing collection of data that indicates sustained climate change for the future.

Since 1976, the symptoms of global climate change have become more evident. The Intergovernmental Panel on Climate Change Fourth Assessment, issued in 2007, reported that the average temperature worldwide has risen by more than 0.7 °C over the past 100 years. Eleven of the past 12 years are among the warmest on record since 1850. As ice sheets and sea ice thin, sea levels are rising by 1.8 millimeters per year. Snow cover in the northern hemisphere has declined by about 10% since the 1960s as mountain glaciers retreat. Meanwhile, weather patterns have shifted significantly, resulting in torrents of rain on some parts of the world while other regions have experienced prolonged periods of drought.

While some long-term assumptions about climate change remain inconclusive, a growing volume of scientific and anecdotal evidence has become a central topic of discussion among scientists, industry, policymakers and the general public. Energy giants such as BP, Chevron and ExxonMobil are now advocates of greenhouse emission cutbacks and energy consumption control measures. Long-time skeptics of nuclear power as an alternative to CO_2-emitting coal-fired plants have reversed their position. As climate researchers fill in the missing pieces of data, public polls reflect a growing belief that climate change is real and should be addressed, although precisely how is unclear to many.

Many elected officials are understandably demanding that climate researchers provide concrete answers, given the immense economic and social costs required to mitigate climate change or to adapt to projected consequences of sustained warming. Forecasts of climate change, although improving, still strive for greater accuracy and detail regarding what impacts will occur, where they will occur, how severe they will be, and how fast they might occur. Earth's complex biological, environmental and socioeconomic systems often reveal their secrets hesitantly. The challenge for the scientist is to understand these highly complicated systems and represent their complexity accurately and dispassionately.

PLEX

ORNL is marshaling talent for one of humankind's most important studies.

In at least one important respect, climate change is an energy issue. The large majority of scientists agree that CO_2 derived from fossil fuel use is a primary forcing factor in global warming. Increasing CO_2 concentrations in the atmosphere cause more of the sun's radiation entering the atmosphere to be trapped, creating the "greenhouse" effect. Increasingly, researchers are addressing questions regarding the precise interactions among emissions, the atmospheric chemistry and the capacity of terrestrial ecosystems and oceans to take up atmospheric CO_2. A further challenge is to address other atmospheric components such as aerosols that can create a cooling effect. Resolving these and other questions requires that climate scientists measure, experiment and model this complex system with tools that have become available only in the last few years.

After early evidence several decades ago from the Hawaiian Mauna Loa CO_2 monitoring record demonstrated consistently increasing levels of carbon dioxide in the atmosphere, researchers at ORNL and elsewhere began their climate-related research with the simple quest to track the carbon—where the emissions were coming from, where they were going and how much ended up in the atmosphere.

"Originally, we called this the missing carbon," says Gary Jacobs, who heads up ORNL's environmental research efforts. "We could measure and estimate what was in the atmosphere, and we had a handle on the global emissions. The difference in the two had to be the carbon dioxide that was being taken up by terrestrial ecosystems and oceans. Our challenge has been to quantify those values and understand how they might be changing over time."

This question evolved into one of how increased amounts of carbon dioxide in the atmosphere would affect ecosystems that provide valuable resources—food, fiber, fuel, recreation— to Earth's inhabitants and how their dynamics would affect the amount of CO_2 and other greenhouse gases in the atmosphere. In experiments, researchers must examine CO_2 as a source of change by itself and link the greenhouse gas with the expected results of global warming—higher temperatures and altered rainfall patterns.

"Clearly it is necessary to foresee more accurately the consequences of the continued use of fossil fuels by: 1) learning more of the carbon cycle…; 2)most importantly, learning more about the climatic (particularly regional) effects of increased atmospheric CO_2 through a greatly increased and integrated climate study effort; and 3) learning how to predict the full impact of a given change in regional climate on man, (the) environment and … society."*—The Global Carbon Dioxide Problem*, 1976

The scientific community is working to answer these questions through the multi-agency U.S. Climate Change Science Program. The Department of Energy hosts research on the integration of atmospheric science, carbon cycle science, ecosystem dynamics, climate change prediction and integrated assessment. ORNL's contribution through DOE as well as a number of other federal agencies has focused upon the terrestrial carbon cycle, ecosystem response to environmental change, associated data archiving, climate change prediction and assessments of impacts, mitigation options and adaptation strategies.

For more than a decade, ORNL has served as a repository and resource for climate change data, storing information that includes carbon dioxide measurements from around the world, ground-truth data for NASA's satellite observations and an archive that offers clues to how climate will change cloud formation and precipitation patterns. ORNL researchers have studied ecosystems and population centers to determine the impacts of human-induced climate change as well as the ways humans could potentially respond to predicted changes in their environment. In addition to the studies of cause and adaptation, another group of ORNL scientists is examining mitigation strategies such as planting bioenergy crops that could counter to some extent the fossil fuel emissions that humans are pumping into the atmosphere.

The intensified research of the past 30 years has led a majority of scientists to agree that climate change is occurring, attributable largely to a geometric increase in greenhouse gas emissions. Still, a number of important questions remain regarding how climate changes from year to year, how fast future changes will occur and how society can best respond to these predicted changes.

Today's scientists have new measurement tools and computational capacity that were not imaginable in the early 1970s. New sensors and sensor networks will enable researchers to undertake a more sophisticated process of monitoring the environment and set up single- and multi-factor experiments to test the assumptions that accompany potential climate changes. Meanwhile, leaps forward in genetics and genomics are helping ORNL researchers to design groundbreaking studies of ecosystems at a molecular level, viewing how the genes of plants respond over time to changing atmospheres and environments.

ORNL's investment in high-performance computing has positioned the Laboratory to become a world leader in climate modeling and visualization. By the end of 2008, the Laboratory will be home to two of the world's largest supercomputers, one funded by the Department of Energy, the other by the National Science Foundation, and both with the capacity to bring new research options to the climate change discussion.

Thomas Zacharia, ORNL's director of computing and computational sciences, says: "With the world's second fastest supercomputer already available at the Laboratory, we have performed studies that project the level of emissions over the next century that would be required to limit global warming to 2°C. As the computer's power expands to a petaflop—that is, 1,000 trillion calculations per second—by 2009, the regional details of climate impacts and key feedbacks with clouds and ecosystems will be available."

ORNL's climate change program includes a growing focus on understanding how new technologies might aid in adaptation to the realities of climate change. ORNL Corporate Fellow Tom Wilbanks served as a coordinating lead author of a chapter in the 2007 Intergovernmental Panel on Climate Change Fourth Assessment report discussing the potential impacts of global climate change on settlements and society.

The Laboratory's adaptation research is complemented by similar efforts to mitigate the nation's carbon dioxide emissions and develop more sustainable energy sources. An ORNL-led team recently was awarded one of three new $125 million Department of Energy bioenergy research centers. The Laboratory is also a leader in the development of energy efficiency technologies for

Photo 1 ***Rich Norby, Christopher Schadt, Aimee Classen, Hector Castro Gonzalez***
Day job: Conduct experiments to discover impacts of climate change on terrestrial ecosystems
Reduce carbon footprint by: Using only compact fluorescent light bulbs at home
Photo 2 ***Lianhong Gu***
Day job: Studies carbon, water and energy exchanges between the atmosphere and terrestrial ecosystems.
Reduces carbon footprint by: Cutting out office air conditioning
Photo 3 ***David Weston***
Day job: Uses genomics tools to observe changes in ecosystems due to climate change
Reduces carbon footprint by: Shopping for local produce at Oak Ridge farmer's market
Photo 4 ***Gregg Marland***
Day job: Studies carbon cycle and lead author on multiple reports of the Intergovernmental Panel on Climate Change
Reduces carbon footprint by: Biking to work

transportation and buildings that could help lessen the growing demand for Earth's finite resources.

"The urgency which we sense from the present study is that decisions of the next few years may block or put off humanity's choices for avoiding drastic changes in the early or middle decades of the 21st century."*—The Global Carbon Dioxide Problem*, 1976

In addition to a variety of environmental and societal impacts, climate change has emerged as a question of national security. ORNL's National Security Directorate recently initiated a project, supported by the Department of Homeland Security, that considers questions raised by prospects of severe environmental events and ways that large and small population centers can prepare for and respond to potential risks.

Our task is to provide accurate and unbiased information to the people who have to deal with one of the most complex subjects of our time.

"We are examining what the literature says about the dimensions of community resilience to natural disaster, and with that understanding we are going to work with three cities as prototypes to see what is necessary to make them more resilient to natural disaster," Wilbanks says. "To me, that is a contribution to climate change research."

On the experimental front, Jacobs says the Laboratory is planning to expand from small, single factor, manipulated experiments to larger areas that better represent existing ecosystems to determine how they respond to higher temperatures, altered rainfall and increased levels of carbon dioxide.

"We are in the process of defining from a climate change perspective the world's six to 12 most important ecosystems," he says. "Experiments in those ecosystems would enable us to begin to isolate the various factors such as temperature versus CO_2 versus precipitation. We could then answer questions such as, how do these factors influence insect populations? How does the microbial community respond and influence ecosystem function and sequester CO_2?"

The 34,000-acre Oak Ridge Reservation is an important resource for much of this research. Recently the reservation was designated a core site for one node of the National Science Foundation's National Ecological Observatory Network or NEON. The network will provide intense and consistent observations of ecosystems across 20 domains in the United States.

"Our research at ORNL," Jacobs says, "does not have to make the tough decisions or set policy. Our task is to provide accurate and unbiased information to the people who have to deal with one of the most complex subjects of our time. The job is even more difficult because the science at times is uncertain, often making it impossible to provide black and white answers as quickly as some would like. Our challenge is to make dramatic strides in understanding the future impacts of climate change. Armed with that understanding, we can then help design mitigation and adaptation strategies for the next generation."—*Larisa Brass*

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KEEPING A RECORD

One of the world's most comprehensive climate databases is a key tool for researchers.

Tom Boden in the Walker Branch Watershed carbon flux tower.

The tower sits atop Chestnut Ridge, offering fabulous views of the East Tennessee mountains and quietly collecting data that are contributing to scientists' view of the future. For every vivid image of hurricanes, drought-cracked lake beds, melting icecaps and coal-fired power plants, there are trillions upon trillions of data points measuring and documenting Earth's vital signs: carbon dioxide and other greenhouse gases, solar radiation, cloud formation, plant growth, precipitation and temperature. Oak Ridge National Laboratory is the repository for a growing inventory of key data that documents the past and present and hints toward the future.

The tower on Chestnut Ridge, for example, is part of the AmeriFlux project, a network of more than 100 towers that measures the movement of carbon, water vapor and radiation into and out of terrestrial ecosystems—forest and vegetation on land and in freshwater streams and lakes. (See sidebar.) ORNL also serves as a repository for the Atmospheric Radiation Measurement program, a Department of Energy project that collects real-time data on, in its simplest terms, clouds and sunshine—important for understanding how climate change may affect or be affecting weather. ORNL manages one of nine NASA Distributed Active Archive Centers, this one a repository of field research data that serves as "ground truth" for the National Aeronautics and Space Administration's satellite measurements of conditions such as fire damage, leaf cover, carbon flux, snow melts and the amount of sunlight absorbed or reflected by a forest or a field of grass.

"We are the only lab for the Department of Energy with major holdings of climatic change data," says Gary Jacobs, who heads up ORNL's environmental sciences research. "We house several archives that promote active research collaboration among the scientific community."

Tom Boden manages the Carbon Dioxide Information Analysis Center, or CDIAC, a data collection built in part through passive instruments taking record of existing conditions as well as through manipulated experiments in the environment, such as the Free-Air CO_2 Enrichment experiment (see article, p. 14), which pumps carbon dioxide directly onto forest plots. Boden stresses the ORNL archives do much more than simply archive and disseminate data. Documenting, validating and enhancing incoming data streams are essential elements of CDIAC data management. Even with all the data streams coming into CDIAC, gaps persist, impeding some modeling efforts. ORNL scientists work with the climate-change community to develop proper modeling and statistical techniques to fill those gaps.

Among climate change circles, CDIAC holds some particularly well-known and unique data sets. CDIAC houses the legendary Mauna Loa record, carbon dioxide measurements initiated nearly 50 years ago atop the Hawaii volcano that first demonstrated rising concentrations of CO_2 in the atmosphere. The CDIAC data collection includes information derived from the ice cores drilled at Vostok, Antarctica, characterizing the nature of climate and climate feedbacks over the past 420,000 years. CDIAC stores rare climate records from China, dating back centuries. One of CDIAC's most popular and contemporary databases, annual releases of CO_2 from fossil fuel burning and cement production worldwide, is built in-house and draws largely on the work of ORNL researcher Gregg Marland and reports provided by the United Nations on international trade and economic activity taking place around the world. These emission estimates were the background for Marland's recently publicized prediction that China will pass the United States this year in CO_2 emissions from fossil fuel combustion in power plants and transportation vehicles.

Boden says over the past 20 years ORNL's databases have gone from being a resource used by a relatively small group of scientists, to an electronically managed archive that responds to information queries from a broad base of people. "We get questions from everyone—premier climate change researchers, congressional staffers and just the general public," he says. "When I first came to ORNL, if we had 500 to 1,000 requests a year we considered the volume heavy. Then, our requests came by mail and phone. Now more than 99% of the requests are direct downloads from our servers and websites. We have 350,000 requests a year—and that number is growing."

ORNL's archives are helping scientists understand the most basic atmospheric and terrestrial cycles and, therefore, how Earth might respond as nature turns up the heat. Take clouds, says Raymond McCord, manager of the Atmospheric Radiation Measurement archive, or ARM. When he began working with the database more than a decade ago, McCord says, "as an ecologist, I thought, okay, we all know how clouds form. But there is a lot scientists did not and do not understand about the interaction of sunlight with water in its various states. This understanding is very important when we think about how higher temperatures could affect the cycles of evaporation, condensation and rainfall—in other words, our weather."

Using instruments stationed around the world, scientists can observe on a minute-by-minute basis the interaction of water in its three forms—vapor, droplets and ice crystals—with radiation as well as the temperature and wind profiles that influence weather patterns. With almost 15 years of detailed and continuous data now collected, McCord says ARM is working with climate modelers to feed the information into high-performance computational models that will help predict how future climate change could alter the world's weather.

A radiometer atop the Walker Branch Watershed tower measures radiation from the sun and sky.

"There is beginning to be enough data to enable climate modelers to identify revised parameters for their current assumptions," he says. "The intersection of our data collections, model development and computational resources will provide us many new scientific methods for climate modeling in the future. ORNL has significant capabilities in data management, modeling and supercomputer implementation that should enable new discoveries in climate change research."

In addition to the wealth of historical data housed in ORNL's archives, researchers are also launching new projects to help catalog the world's natural phenomena. One such project is the USA National Phenology Network, a partnership of multiple government agencies and research institutions being set up to study the annual cycles of plants and animals. The project includes recording observations of budding, birth, migration, growth and other visible, physical characteristics of life on planet Earth.

"Such information is highly interrelated with climate change," says Bruce Wilson, who is leading the development of cyberinfrastructure for the archive. "For instance, earlier leafing due to global warming combined with drought can create conditions more vulnerable to forest fires, which in turn can affect the climate."

Because phenology is everywhere, the U.S. National Phenology Network is attempting to complement the data from towers and modern instruments by using the power of everyday Americans' observations of the environment. Some tools already exist to allow people to observe and submit phenology measurements on native plants in their regions, such as the common lilac. The program is also working to expand the types of observations that citizen scientists can contribute, going beyond plants to insects, animals and birds, as well as providing standardized cultivars of indicator plants to make observations more comparable across the nation. This is the first time in America, Wilson says, that there has been a coordinated, standardized effort to gather such data, although similar networks have been long established in European countries.

"Using citizen scientists is an excellent way to get the wall-to-wall, coast-to-coast data that will help provide a big picture of how climate change may be affecting a variety of ecosystems across the country," he says. He is working to complete the first phase of cyberinfrastructure for the project in time to catch the 2008 growing season, with further expansion to continue beyond that—dependent, of course, on funding.

Such partnerships among large groups of organizations and people are "how much of science will get done in the future," Wilson says. "This is an exciting story."—*L.B.*

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TOWERS OF KNOWLEDGE

A radio tower? A cell-phone tower? No, it's a flux tower.

Climate and biogeochemistry models honed to run on ORNL's world-class supercomputer are fed data on air-surface exchanges of carbon dioxide, water vapor and energy. A global network of more than 400 micrometeorological tower sites measures these exchanges of two greenhouse gases and solar radiation between the atmosphere and terrestrial ecosystems. Researchers also collect data on the vegetation, soil, hydrologic and meteorological characteristics of tower sites.

Two towers are located on the Oak Ridge Reservation's Chestnut Ridge and Walker Branch Watershed. Tower site data are downloaded, processed and archived at ORNL for DOE's Carbon Dioxide Information Analysis Center.

Sensitive instruments suspended on these "flux towers," some almost as tall as 200 feet, measure tiny CO_2 fluctuations in air columns over a variety of landscapes. The towers, which form a 10-year-old U.S. network called AmeriFlux, provide carbon cycle modelers with essential data on exchanges involving numerous terrestrial ecosystems worldwide, from forest to grassy field to desert.

FLUXNET was formed to coordinate global analysis of flux tower data. FLUXNET data are stored at ORNL at one of NASA's nine Distributed Active Archive Centers. Using FLUXNET data, researchers discovered that the drought linked to the 2003 killer heat wave in southern Europe triggered considerable respiration—accelerated emission of CO_2 to the atmosphere by plants and soil bacteria. The reason: photosynthesis had shut down in response to less water so respiration picked up.

More and more towers are measuring sunlight entering the forest from all directions at low angles because of a recent discovery by ORNL's Lianhong Gu. He found that diffuse solar radiation scattered by airborne volcanic ash enhances photosynthesis in plants shaded from direct sunlight by leaves in the forest canopy. Moderate cloud cover and sulfate aerosols injected into the atmosphere by coal-fired power plants can increase diffuse radiation. Accurate estimates of the resultant enhanced photosynthesis in the lower forest help scientists predict more precisely the amount of carbon that will be stored in the forest soil.

Advances in instrumentation and data collection over the past 30 years have greatly improved flux measurements. The number and accuracy of flux measurements, like each new tower, will go up. —*C.K.*

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MODELING THE F

Supercomputers produce breakthroughs in climate research.

Heat waves and heavy rainfall will be more frequent. Sea ice near Earth's poles will shrink. Tropical hurricanes will become more intense, with higher wind speeds and heavier precipitation.

Earth's surface will continue to warm, increasing on average 1- 3°C globally, 7-10° in the polar regions and virtually 0°C near the equator. The oceans will continue to rise slowly over the next millennium as a result of past and projected carbon dioxide emissions from human activities, such as destruction of forests and fossil fuel combustion in power plants and transportation vehicles. Each CO_2 molecule generated will survive for nearly 100 years in the atmosphere before being permanently removed by terrestrial photosynthesis or diffusion in the ocean.

In 2004-05 the Department of Energy's Center for Computational Sciences at Oak Ridge National Laboratory provided an important contribution to a suite of climate modeling simulations from 15 nations, helping develop predictions in response to questions posed in an international investigation of Earth's climate. In February 2007, the first report of the fourth assessment of the United Nations' Intergovernmental Panel on Climate Change was released in Paris, France. The report, which received wide coverage by the world's news media, concluded that evidence of a global warming trend is "unequivocal" and that increased human emissions of greenhouse gases to the atmosphere has "very likely" been the driving force in that change over the past 50 years.

"What must be done to respond to a dangerous buildup of CO_2 in the atmosphere can be viewed as drastic," remarks John Drake, who leads climate modeling at ORNL, site of the world's most powerful open-science supercomputer. "Humankind must start reducing CO_2 production, returning to almost pre-industrial emission levels of 1870."

In both scientific and societal terms, the challenge is extraordinary. The atmospheric concentration of CO_2 has risen exponentially from 280 parts per million in 1870 to 385 ppm today. Some models predict atmospheric CO^2 doubling by 2100. Even if humankind emitted no more CO_2 after 2100, Earth's temperature would still rise by 2°C, making a warmer ocean so acidic from dissolved CO_2 that coral reefs, which shelter fish and protect shores against beach erosion, could vanish.

Cheetah's calculations

Many of the Intergovernmental Panel's projections concerning present and future climate change and the roles of human activity resulted from runs in 2004-2005 of climate models on ORNL's "Cheetah" supercomputer. The simulations supplied calculations for more than 200 papers, including several from ORNL, for the first report of the fourth IPCC assessment. Cheetah is an IBM Power4 supercomputer with a peak capacity of 6.4 teraflops, or 6.4 trillion calculations per second.

UTURE

According to the 2007 report, projections of computer models closely match observed temperature increases of "about 0.2°C (0.36°F) per decade, strengthening confidence in near-term projections." Observed trends indicating climatic warming include more moisture in the air, less ice and snow on land, less Arctic sea ice and rising sea level.

Two U.S. organizations supporting the Intergovernmental Panel on Climate Change developed models for running energy scenarios that assumed both high and low greenhouse gas emissions. The goal was to predict changes in temperature and precipitation up to the year 2100. One group was a National Oceanic and Atmospheric Administration center in Princeton, N.J. The other organization, which interacted with university, ORNL and other national lab researchers, was the National Center for Atmospheric Research in Boulder, Colo.

With funding from the Department of Energy, ORNL researchers led by John Drake and David Erickson dedicated fully one-third of Cheetah's processing time to climate modeling in 2004-2005. Over the same period, NCAR's runs, funded by the National Science Foundation and DOE, consumed an additional one-third of the supercomputer's processing time.

"Every nation ran the same emissions scenarios as the U.S. using their own models," says Drake. "In that way we addressed a range of uncertainties." ORNL's primary responsibilities included developing computer codes and fine-tuning the U.S. models to make sure they could run the agreed-upon scenarios on Cheetah. The project produced 100 terabytes of data that were posted and stored on DOE's Earth System Grid. Some data are archived at ORNL's Leadership Computing Facility, a node on this grid.

Code contributions

From 2002 to 2004 Drake and his ORNL team contributed to the development of the Community Climate System Model used by researchers worldwide in support of the Intergovernmental Panel on Climate Change. University researchers can obtain the model and participate in its development and use for simulations.

Climate models represent the complex systems and interactions of the atmosphere, oceans, land and ice fed by solar energy. The physics parts of the models predict Earth's surface temperature based on the degrees to which solar radiation warms Earth's surface, provides heat absorbed by the oceans, reflects off land surfaces, ice sheets and atmospheric particulates, and warms the atmosphere. This warming occurs as carbon dioxide and other greenhouse gases in the atmosphere trap solar infrared radiation that Earth returns to the air. The accuracy of the models is tested by seeding them with actual greenhouse gas data from the past 30 years and determining how closely the predicted results match recorded temperatures.

Climate models also simulate dynamics, particularly atmospheric and ocean circulation that drives changes in temperature and precipitation. ORNL has focused on atmospheric circulation and land interactions. DOE's Los Alamos National Laboratory has modeled ocean-air interactions. General circulation models calculate the three-dimensional distribution of winds and currents that move CO_2 and other chemicals through the climate system.

For the Community Climate System Model, Oak Ridge researchers wrote algorithms, or mathematical methods, for solving flow equations, an area of ORNL expertise. ORNL researchers developed flow equations for simulating winds blowing in the atmosphere and the River Transport Code, a river routing scheme that calculates the freshwater balance.

"Ocean circulation depends on salinity as much as on temperature and wind," Drake says. "Salt influences water density, which affects water flow rate. In a coupled land-ocean model, this code collects rain falling in the land model and routes it through the simulated river system to the right places in the ocean. By determining freshwater input into the ocean, the model can accurately calculate the relative proportion of salt in the ocean. Developing a sound hydrology prediction in the model was a major contribution."

Heating and cooling

ORNL's David Erickson asked an important question: "Could climate change actually accelerate if people use more energy to stay cool as temperatures rise?"

Erickson and ORNL engineer Stan Hadley were the first to integrate energy-economic and climate models to evaluate the influence of climatic warming on energy use. They plugged a standard climate model's temperature predictions for 2000 to 2025 into the National Energy Modeling System developed by DOE. The researchers published their results in the August 2006 issue of Geophysical Research Letters.

The modeling system calculates energy requirements for heating and cooling all buildings in every county of the United States. The program takes into account each locale's climate, building styles and fuel sources for heat and electricity. The results range from predictable to surprising.

Predictably, the study projected that CO_2 emissions would rise as more coal is burned to produce additional electricity required for air conditioning during ever-warmer summers in the South and West. However, despite climatic warming in the Northeast, the winters would not be warm enough to reduce significantly residents' need for heat from natural gas and heating oil. The net result: over the next 25 years, increases in carbon emissions from higher air conditioning demands in the South and West will more than offset decreases in carbon emissions from reduced heating needs in the Northeast. Thus, CO_2 emissions will edge up even more in three regions of the United States.

Erickson is interested in improving detailed climate models by including another aspect of heating and cooling. He has written algorithms for simulating the heating and cooling effects of aerosols, particles formed from collections of atoms and molecules that compose clouds and float in the air.

His model will simulate interactions between different wavelengths of solar radiation—from infrared to visible to ultraviolet light—and a variety of atmospheric aerosols. Some sulfate aerosols from coal-fueled power plants reflect solar radiation in most regions of the spectrum, cooling the atmosphere locally. Other aerosols absorb certain radiation wavelengths, exhibiting a warming effect. Erickson takes into account a variety of aerosols, ranging from sea salts and African desert dust blowing across the ocean to air pollution sulfates and haze-producing organic isoprene shed by tree leaves that gives the Great Smoky Mountains its name.

Earth systems models

ORNL climate researchers are developing "earth systems models" that simulate a fully interactive carbon cycle. By merging biogeochemical models with a climate model, researchers are developing a model with several layers of complexity. The Earth Systems Model will represent not only the physics of solar energy and the atmosphere and the dynamics of air and ocean circulation but also biogeochemical cycles and socioeconomic data, such as population density and land-use statistics.

The climate model will start in 1870 and include CO_2 emissions and land-use changes up until the present. The sophisticated model will compute, from pre-industrial to the present, CO_2 emissions from forest fires and decomposing fallen trees, as well as the amount of CO_2 absorbed for photosynthesis every 20 minutes as different plants throughout the world respond to changing emission, temperature and moisture levels. The goal of the project is to determine whether the model will compute Earth's current atmospheric CO_2 level of 385 ppm based on the incorporated carbon cycle data and algorithms. To accurately predict the current atmospheric CO_2 level will be a challenge that will require collecting all the needed data and measuring the carbon pools with precision.

ORNL researchers are collecting data from all over the world about the types of plants that have grown in various regions between 1870 and the present. They also are seeding the model with flux tower data on air-surface exchanges of CO_2, water vapor and energy (see sidebar on p. 9). They will calibrate earth systems models for 15 different ecosystems, types and rates of inputs and environmental conditions and then make global-scale calculations on the CO_2 exchanges between the terrestrial ecosystems and the atmosphere.

Coupled climate and carbon cycle models run on more powerful supercomputers will likely be used to predict global temperature changes between 1870 and 2100. The predictions will be based on greenhouse gas emissions and absorption through photosynthesis, respiration and historical and projected releases of CO_2 from fossil fuel combustion and deforestation.

Merged models using data from ORNL sources will be used to predict how much a warmer climate and an atmosphere with elevated levels of CO_2 will raise rates of photosynthesis and soil decomposition, which in turn will boost atmospheric CO_2 levels even more.

Enhanced photosynthesis by increased atmospheric CO_2 concentrations is limited by the amount of nitrogen available in the soil to form the enzyme that drives photosynthesis. ORNL's climate team seeks to model a tree's response that may be hampered by reduced nitrogen availability except for regions receiving anthropogenic deposits from transportation vehicle exhaust and fossil fuel power plant emissions.

Their effort includes computer models that globally simulate leaf fall and the death of forest trees and grasses, their decomposition by bacteria and fungi in the soil, physical protection of the soil carbon and the eventual release of the soil carbon back to the atmosphere. The polar regions have three times as much soil carbon as the Southeast. With warming, models will predict a shift in the carbon balance as polar soils decompose faster, release more carbon and host many new plants that take in atmospheric CO_2 for photosynthesis.

For the last runs for the Intergovernmental Panel on Climate Change, the modelers had adequate data to predict heat waves for various regions. What the massive computers lack is sufficient resolution to predict accurately the frequency of hurricanes over many years. Hurricanes contribute a significant amount of rainfall to the Southeast. Projecting their frequency correctly over a century would help modelers predict precipitation with greater accuracy in the Southeast so that simulated green plants would grow in the right places.

In one modeling run, clearing of rainforests along the Amazon River reduced transpiration, resulting in fewer clouds and less rainfall. The data generated fear that Amazonian rainforests could become so warm and dry by mid-century they will essentially collapse. As a result, through respiration the dying forest plants would accelerate releases of CO_2 to the atmosphere.

New questions

As more data become available, the questions in the climate discussion are shifting. Initially, scientists sought to understand what might happen to the climate in the next 100 to 500 years. With increasing frequency, the same scientists are attempting to answer how, over the next 20 to 50 years, society will be forced to adapt to the environmental impact of a continued buildup of CO_2 in the atmosphere.

ORNL's John Drake says, "People are now seeing the effects on local scales. We may not see the effects in the Southeast in our lifetimes. But in higher latitudes such as Alaska, Canada and Greenland, people are seeing effects now, such as more rapid melting of ice sheets."

Drake anticipates that ORNL's climate modelers will continue to be asked for additional projections on the effects on climate of different levels of greenhouse gas emissions from various energy scenarios. Policymakers seeking evaluations of different mitigation options may request scenarios that include replacing fossil fuel power plants with nuclear power plants, using carbon capture technologies on coal-fueled power plants and growing vast tracts of switchgrass for producing ethanol to replace gasoline. As the debate continues, ORNL researchers will be providing scientifically grounded predictions about one of the most important issues of our time.—*Carolyn Krause*

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TESTING Nature

Today's experiments help inform tomorrow's climate models

Courtney Campany records field data at OCCAM experiment.

When the Free-Air CO_2 Enrichment, or FACE, site was planted with 6,000 sweetgum tree seedlings in 1988, Colleen Iversen was nine years old.

Today Iversen, a University of Tennessee graduate student and Department of Energy Global Change Education Program Fellow, is conducting research on the Oak Ridge National Laboratory site where the trees have been fed a diet of carbon dioxide at levels approaching those anticipated in the coming decades. Through FACE and other long-term experiments, Oak Ridge National Laboratory has become a leader in demonstrating the potential effects of global climate change on terrestrial ecosystems. By establishing experiments that manipulate environmental conditions associated with atmospheric and climate change, ORNL researchers are uncovering clues about how trees, plants and the soils that hold them could be affected.

"ORNL is a world leader in research on terrestrial climate change response," says Paul Hanson, an ORNL ecologist who has studied the effects of both drought and increased rainfall on eastern forests. "Terrestrial response to climate change is our bread and butter and is recognized as such."

From fields to forests, a variety of experiments at ORNL has enabled researchers to peek into a future characterized by higher temperatures, changes in levels of rainfall and higher concentrations of carbon dioxide in the atmosphere. Scientists can reasonably predict future levels of carbon dioxide and potential warming trends, and have conducted experiments to reveal how plants will respond. There remains, however, much uncertainty about how these changes will affect entire ecosystems, from the production of trees and plants to carbon storage to the availability of other nutrients in the soil. ORNL experiments are contributing to the fundamental understanding of how the components of ecosystems—from the wood and vegetation above the ground to the roots and microbes beneath—function as a whole.

"We started with very-small-scale studies in the growth chamber, and that transitioned to open-topped chambers in the field and ultimately to the FACE experiment," says Stan Wullschleger, who leads ORNL's plant molecular ecology group. "The group's research has evolved from small-scale, short-term studies to current,

large-scale, long-term experiments designed to understand the physiology and the ecology of ecosystems."

Single factor experiments

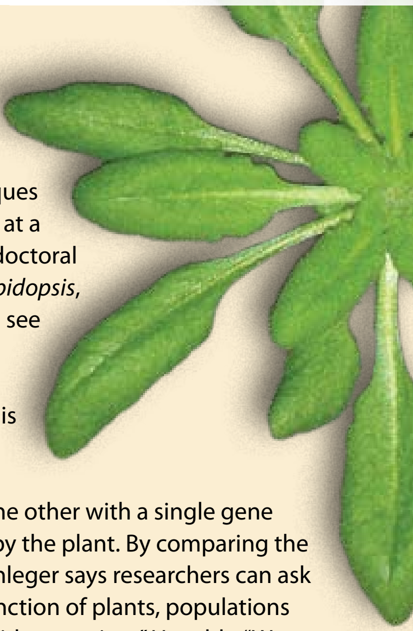
FACE is one of the longest-running experiments at ORNL. For the past 10 years sweetgum trees on a 4.2-acre site have been exposed to elevated levels of carbon dioxide in an effort to determine what effect this greenhouse gas would have on a real-life ecosystem. ORNL is one of several FACE sites. Others include a loblolly pine stand located at Duke University; a desert plot in Nevada; aspen and birch stands in Wisconsin and a soybean field in Illinois.

In 2004, Oak Ridge National Laboratory published findings in the *Proceedings of the National Academy of Sciences* showing that increased carbon dioxide levels in the air cause trees to produce more fine roots and leaves. Uncertainty about the effect of CO_2 on terrestrial plant life was an important limitation of climate change models being generated to predict the potential impact of a warming earth, says Rich Norby, an ORNL Corporate Fellow who oversees the FACE project.

"CO_2 is the primary driver of the greenhouse effect," Norby says. "We always keep in mind that our experiment does not replicate the future. You can make big mistakes by trying to pretend the research is more than it is. The objective is an understanding that can be used to inform ecosystem models. We want the models to be informed by real-world observations that are realistic."

Now researchers including Iversen are focused on discovering what that means for the world of soil, water, roots and microbes underground. "We do not know a lot about the interchange between plants and soil," information that could provide answers to questions about the ultimate effect of carbon dioxide on the growth and decomposition of trees and on the effectiveness of soil in sequestering carbon, Iversen says. "Researchers refer to underground processes as the 'black box.'"

Another key piece of a changing climate is precipitation. While scientists do not yet know with certainty how levels of rainfall will be affected by a warmer world,



News Ways to Look at Nature

With the improvement of genetic analysis tools over the past decade, researchers are now experimenting with techniques to examine how plants respond to climate change conditions at a molecular level. ORNL researcher Stan Wullschleger and postdoctoral researcher David Weston have set up an experiment with *Arabidopsis*, one of three plants whose genomes have been sequenced, to see how the plants respond genetically to higher levels of CO_2.

"I tend to think of our experimental work at ORNL as the tale of two scales—genes and ecology," Wullschleger says. "This project offers small-scale insights into big-time problems."

The experiment employs two types of *Arabidopsis* plants, one with a complete complement of genes as a control and the other with a single gene deleted to influence the uptake and assimilation of nitrogen by the plant. By comparing the two types—grown in monocultures and in mixtures—Wullschleger says researchers can ask unique questions about how genes potentially control the function of plants, populations and ecosystems along with "the goods and services they provide to society." He adds, "We are studying ecological properties and processes at the level of the gene. We think there is value in looking at some of these ecological questions at that very basic, fundamental scale."

Wullschleger and Weston use systems biology, physiology, biochemistry and ecosystem measurements to characterize how the plants interact from one generation to the next, to track the relative abundance of the two different types from one generation to the next and to understand how gene-level changes translate to populations and ecosystem processes. Early results show that altering the expression of a single gene impacts carbon and nitrogen metabolism, which, in turn, leads to delayed flowering and reduced seed production. These effects translate to rapid shifts in plant composition and probable impacts on nutrient cycles. Three generations of plants have been grown in the mesocosms located in the ORNL greenhouses. The researchers hope to complete 10 to 15 generations of growth in the coming years.

The project's most exciting potential, says Weston, is that the systems biology approach will unearth a storehouse of information that could affect models and even mitigation responses to global climate change. "The genome is an integrated history of the organism, representing the evolutionary response to selection pressures that have happened from the time that these land plants actually began," he says. "If we can unlock that potential and see the genomic code behind adaptive mechanisms to past climates, we will have the potential to use that information to predict plants' behavior in future climates."—*L.B.*

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Hanson has examined two possible scenarios for forests of the eastern United States and Tennessee in particular. In a study begun in 1993 and completed early last year, Hanson and his colleagues altered rainfall over plots of trees located on the acreage surrounding ORNL, providing some plots with a 33% increase in precipitation and others with a 33% decrease.

The researchers are now in the process of publishing the study's final conclusions. Hanson said the experiment showed that because of their deep, established root systems, large trees are highly resilient and drought tolerant. However seedlings are more likely to die in drought conditions.

"Future rainfall changes do have a potential impact, but the impact is not going to be one that we observe as a catastrophic change that produces a die-off of the existing eastern forests. In the absence of a major disturbance event, it would take about 100 years or so for changes in the forest to be observed," Hanson says. "Drought does, however, have the potential to change long-term composition of biodiversity in the forest."

"We are dependent upon modeling results to project what the future might look like and therefore how society might prepare for climate change,"

Information from experiments like FACE and the precipitation projects help inform models that combine the results for a more comprehensive outlook. "We are dependent upon modeling results to project what the future might look like and therefore how society might prepare for climate change," Hanson says. "One of the things we've done is use modeling to combine results from single-factor manipulations into combined analyses of multi-factor effects. We have combined experimental lessons learned from precipitation change, ozone increase, nitrogen input, warming and elevated CO_2 studies and run them through models to reveal a collective response. Those results reveal important interactions.

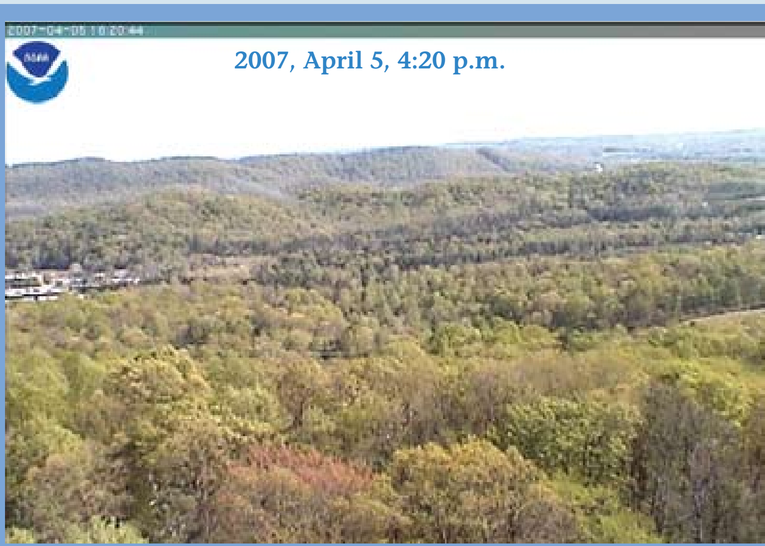
"If we just simulated a CO_2 study, the data would predict a beneficial future. If we simulated only warming, we would find more negative impacts. But if you look at these factors together, they can mitigate or counter one another."

THE 2007 EA

The death and resurrection of tree buds and the rapid wilting of new blossoms as a result of the Easter freeze of April 7-9, 2007, shocked many long-time residents of Alabama, Georgia, Kentucky and Tennessee. With temperatures dipping to 22°F for two consecutive mornings, the spring freeze was the worst in memory. What many locals referred to as a "cold snap" offered an excellent opportunity for regional scientists to understand better how potential extreme weather events brought about by climate change might influence growth of forests, grasses and other species of terrestrial ecosystems.

"We had an early warm spring in March that led to early bud break and leaf development," ORNL researcher Paul Hanson recalls. "Then in early April a cold air mass swooped down from Canada and froze the tree leaves and branches.

"Aircraft and satellite images revealed that the once-green forest canopy turned brown and stayed brown for more than three weeks. Then the trees, grasses and shrubs showed their resiliency and started to kick back. By mid-June all species had shown recovery."



Technician Emmi Felker-Quinn walks through the FACE site.

No Occam's razor

A newer experiment sitting adjacent to FACE's sweetgum stands takes a real-life look at changes that occur from multiple factors associated with climate change including carbon dioxide, temperature and precipitation. Because such conditions are not yet possible to reproduce in multi-acre-sized plots like FACE, ORNL researchers have set up a series of chambers known as the Old-field Community Climate and Atmosphere Manipulation experiment, or OCCAM—a tongue-in-cheek play on the "Occam's razor" principle that the explanation of any phenomenon should make as few assumptions as possible.

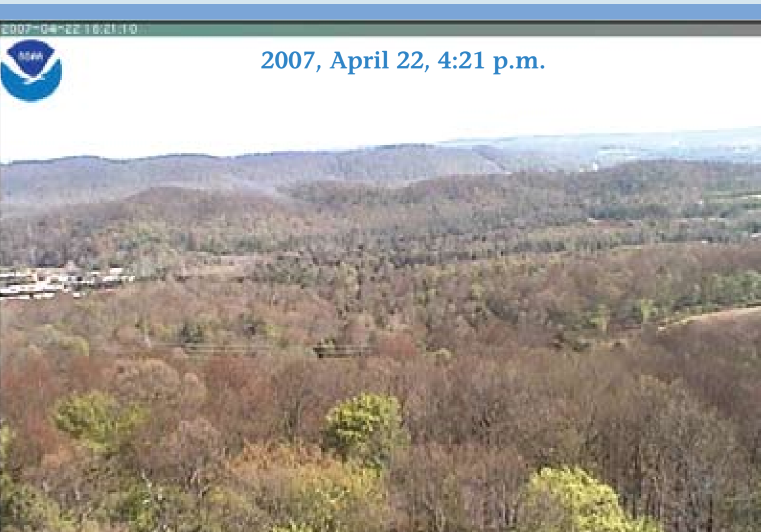
At OCCAM, 12 four-meter open-top chambers house a variety of plants found in Tennessee old fields including wildflowers, grasses and, more recently, a sprinkling of tree seedlings. The treated chambers receive four combinations of high or low carbon dioxide and higher or lower temperature—the higher temperature treatment is 3.5°C above ambient. Each chamber is divided in two, with one side receiving less moisture than the other.

Using sensors and a regimen of regular measurements, a collaboration of ORNL and University of Tennessee scientists is observing how these multiple factors change the phenology of the plants—such as production, flowering and leafing times; the chemistry and resulting impact on plants' decomposition; effects on systems beneath the soil such as nitrogen fixation and changes in the amount of particular species present.

"We have watched two of the plant species change significantly over the course of the experiment, with one becoming dominant and one declining for a while and then coming back," says Aimee Classen, a soil ecologist at ORNL and UT whose primary interest is in aboveground and belowground interactions. "We have also seen impacts on the nitrogen budget in our experiment. Researchers do not fully understand the phenomena, but it is very important. If plant carbon increases as a result of elevated levels of CO_2, in order to maintain that plant growth you must have nitrogen. The question is, where is the extra nitrogen going to come from?"

Experiments such as OCCAM reveal both how little is known about future ecosystem response to climate change and the importance of future scenarios including multiple variables. "OCCAM is not straightforward, which is an appealing aspect of the project," Classen says. "What is particularly exciting about multi-factor experiments is that they are difficult to interpret. We could simplify our system to produce seemingly clear answers. In the long run, however, that would tell us very little about a large and complex problem."—*L.B.*

STER FREEZE



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The biggest surprise, Hanson notes, was that the yellow poplar was the last tree species to recover. While dogwood flowers got hammered, their tree foliage survived. Red maple leaves also survived because they were developed enough to have sufficient sugars to avoid being chilled to their freezing point.

"Freeze damage of non-native garden plants planted too far north is relatively common," Hanson says. "But a freeze event that affects natural systems like an entire forest is quite unusual."

ORNL researcher Lianhong Gu says his studies with Hanson of the Easter freeze's after-effects demonstrate the importance of the heat storage capacity of large forests and lakes.

"We observed that plants inside large forests fared better and did not suffer as much damage as plants in open areas such as home gardens," Gu says. "The heat capacity of the Oak Ridge Reservation's wooded areas helped protect small trees, shrubs and grasses inside the forest from freezing. Another phenomenon we found is that plants along the edge of a large lake did not suffer as much damage as did plants farther from the shore and out in the open."—*C. K.*

Life in a Warmer Land

Modeling climate change impacts can guide long-range, regional planning.

In the 19th and early 20th centuries, a mosaic of mixed forests flourished throughout East Tennessee. Areas that had been burned or otherwise disturbed often supported pines. Alongside pine trees grew specialty hardwoods. White oaks were prized for making barrels. Black oak, maple and hickory woods were ideal for kitchen cabinets and furniture. Basswood made fine hardwood floors.

A series of droughts since 1980 killed thousands of hardwood trees, which were replaced by fast-growing pines. As a result, pine emerged as the commercial wood of choice in much of Tennessee, especially for building construction and manufacture of paper products.

During this period, timber companies purchased thousands of acres of land and replaced the previous blend of mixed hardwood and pine forest lands with an environmentally less friendly tree monoculture. One consequence was that many animals that had adapted to native hardwood forests avoided pine plantations.

By 2003, pine plantations covered 80,000 acres, or about 13% of the land cover in five southern Cumberland Plateau counties between the Alabama border and Sewanee, Tenn.

Drought-weakened and densely planted pine plantations contain trees that are vulnerable to a deadly insect predator. In one of the largest pine beetle outbreaks in recorded history, infested trees rapidly died and fell over. In some locations, wildfires ripped through pine forests, leaving hundreds of acres of charred land.

In 2005, Bowater, a timber company with a paper mill located in Calhoun, sold more than 300,000 acres on the Cumberland Plateau to private developers and the state of Tennessee. On much of the privately owned portion, houses, condominiums and shopping centers are springing up where forests once flourished. For the state portion, Gov. Phil Bredesen has proposed planting native hardwood forests after the timber is harvested.

Disturbances and human intervention

Virginia Dale, a corporate fellow and environmental scientist at Oak Ridge National Laboratory, knows about disturbances and human intervention and their effects on forest growth. She has witnessed first-hand the disastrous results of planting non-native seeds instead of native vegetation after the Mount St. Helens volcanic eruption of 1980 destroyed the forest around the mountain. Her papers suggest the need for improved ecosystem management in the wake of such disturbances. Familiar with disturbances brought about in Tennessee by drought and insect infestation, Dale and her colleagues have modeled the future of forests, which cover one-third of U.S. land south of Canada. Concerning climate change and pine beetle outbreaks in Tennessee, Washington and Canada, she writes:

"As climate change leads to increased disturbances such as fire or drought, these disruptions are very likely to create the type of environment ripe for the spread of invasive species. Insects and pathogens, by virtue of their mobility and short reproduction times, can respond to climate change much more rapidly than tree populations. As a result, insects and disease are likely to cause some of the early impacts of climate change on forests."

Dale's team has been examining several scenarios in which a warmer, drier climate interacts with land use. In Brazil, the clearing and burning of rainforests to provide land for agriculture have released large amounts of the greenhouse gas, carbon dioxide, into the atmosphere. Through this and other similar examples, Dale has become acutely aware of the unintentional

Virginia Dale studies the potential effects of changing climate and land use on environmental conditions, such as water quality.

impacts well-meaning land-use policies can have on climate and the ecosystem.

At ORNL a recent climate change study of Tennessee divided Tennessee into five ecological zones. The study projected that southern mixed forests would change the most, with loblolly pines becoming much more dominant when drought occurs.

Dale and her colleagues have projected the effects of climate change in 2030 and 2080. Their climate projections are combined with expected changes in land cover and land use in the region from Oak Ridge to the Kentucky border, which includes the Cumberland Plateau. Using computer modeling, the researchers produced colorful maps in which "green" forests shrink, yielding to an expanding transitional area speckled with "red" urban, suburban and "exurban" communities with populations growing along roads. Enhanced by this graphic illustration, the potential effects of changing land use on water quantity and quality are striking.

"Scientists ideally should model entire regions to understand the key patterns," Dale says. "How various ecosystems around the world respond to drought will be different. We need to start with a system perspective, add an interface between scientific understanding and government policy decision making and place each region in the context of socioeconomics, human health and aspects of anticipated global change."

For example, a warmer climate could cause tree species to move away from the equator and toward more polar regions. Sugar maple trees, which are abundant in New England, are expected to shift gradually north to Canada, affecting in different ways the economies of both regions.

Southeastern mixed deciduous forests—oaks, hickory and pine trees—are projected to expand under moderately warm scenarios. Under hotter climate scenarios these forests could be transformed into savannas and grasslands.

Some projections suggest that today's atmospheric CO_2 concentration may double by 2100. At least a portion of the consequences of this increase is not clear. According to ORNL researcher Paul Hanson, a synthesis of laboratory studies, field experiments and modeling indicates that forest productivity could actually rise in response to the fertilizing effect of elevated atmospheric CO_2. Furthermore, changes in temperature and water availability could enhance plant growth. One difficulty in predicting effects of climate change on the southeastern United States is that some models project drier conditions while others project wetter weather.

Across a wide range of scenarios, the data indicate that modest warming will lengthen the growing season and boost carbon storage in most U.S. forest ecosystems. In the Southeast, however, greater warming could lead to losses of carbon, possibly exacerbated by more forest fires. Climate and ecological models suggest that overall forest productivity and yields for forest product industries could increase nationally, even as some regions experience declining productivity.

The possibility of a warmer, drier climate brings the possibility of other changes that are unclear. Current ozone levels have reduced wood production by 5% in southern pine plantations. In the Great Smoky Mountains National Park on the border of Tennessee and North Carolina, a negative impact on forest growth from increased ozone could be offset by additional CO_2 and nitrous oxide from coal-fired power plants and vehicle emissions. The offset could supply plants with the nitrogen needed for photosynthesis.

Forests are essential to providing clean water, moderate stream flows and aquatic habitats. With increased temperatures, longer growing seasons and greater leaf area, vegetation would take up more water that would escape to the atmosphere as water vapor, even though elevated CO_2 increases water-use efficiency. Increased transpiration reduces runoff.

Managing a disturbed ecosystem `

"Managers typically try to manage the ecosystem after a disturbance, not before it happens," Dale says. "They often try to fix the problem by moving the ecosystem back to the way it was before the disturbance. What we have learned is that often we cannot move the ecosystem back to the original status."

Dale believes policymakers face a fundamental decision of whether to wait until the impacts of climate change occur or to attempt as best they can to manage the ecosystem or influence the change to produce a more desirable outcome.

"Think about climate, land use and invasive species in forests. Can we manage them as a system? Can we mitigate climate change by reducing carbon dioxide emissions? Should we adapt to a warmer, drier climate by harvesting trees that are not resistant to drought and invasive species, and planting trees that are?"

Dale believes policymakers should anticipate large infrequent disturbances while researchers continue to develop more sophisticated models for more powerful computers to project potential environmental effects of regional land-use changes in a warmer land. For both groups, the stakes could not be higher.—*C.K.*

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FROM PREDICTION TO RESPONSE

Researchers are now studying ways of adapting to climate change.

From the perspective of the Intergovernmental Panel on Climate Change, the question of whether global climate is changing has been resolved. The panel's findings indicate that virtually every glacier in the world is receding and the global sea level is rising as the result of a sustained increase in average temperature. Many biological systems are changing as well, along with the livelihoods of indigenous populations in polar regions.

The panel's 2007 report states that climate changes are expected to continue throughout the 21^{st} century. Increasingly, the extent of these changes, and the degree to which climate changes might be mitigated, are becoming the focus of climate research. Perhaps the most significant shift in the focus of climate research is exploration of ways societies and natural ecosystems might adapt to anticipated, long-term changes in regional climate patterns.

Mitigation and adaptation

For years the U.S. government has generously funded climate research and, on a smaller scale, studies of mitigation options. Mitigation seeks to lower the risks of climate change by reducing greenhouse gas emissions and slowing deforestation, which releases 20% of the carbon dioxide emissions to the atmosphere. Mitigation options include reducing the use of fossil fuels by relying more on carbon-free nuclear power, solar and wind energy for electricity, and biofuels and batteries for transportation. ORNL researchers are at work on mitigation technologies to improve energy efficiency; increase the uptake of carbon by forests and vegetation, soils and the ocean and enable the capture and sequestration of CO_2 during fossil-fuel combustion and conversion processes.

Research focused on vulnerability and adaptation to climate change has received comparably less funding, primarily because of the intensity of effort to determine if climate change is, in fact, an aberration or a long-term phenomenon. Adaptation research has been limited in part by the concerns of some that adaptation prospects might undermine a commitment to climate change mitigation efforts, says ORNL Corporate Fellow Tom Wilbanks, one of 47 coordinating lead authors of chapters for the impacts, vulnerability, and adaptation report of the IPCC fourth assessment. Wilbanks co-led the chapter entitled "Industry, Settlements, and Society," which includes a section about actions communities can take to reduce exposure to climate change risks.

"Now that we see climate change actually happening, we cannot avoid adaptations to some impacts while we try to avoid others," Wilbanks notes, adding that in this context adaptation means learning to live with the impacts of climate change. Improving emergency response capabilities is one example of an adaptation strategy.

More than one-half of the U.S. population lives in coastal communities that are vulnerable to flooding if sea levels rise substantially or if hurricanes bring increased amounts of rainfall. Short-term responses for large coastal cities include the decision to build storm-surge barrier seawalls after weighing the risk of frequent flooding against a cost that many might view as prohibitive. A longer-term strategy might be to raise coastal structures over a period of half a century and to encourage changes in land-use policies to reduce exposures in especially vulnerable areas.

Between 1999 and 2003, Wilbanks and his ORNL colleagues pioneered the idea of developing new climate change response strategies by integrating analyses of mitigation and adaptation. The result was an article for a special June 2007 issue of the international journal, *Mitigation and Adaptation Strategies for Global Change*, of which Wilbanks was one of three guest editors.

Stating that "both mitigation and adaptation are needed in responding to risks of impacts from climate change," the article argues that mitigation "is essential in order to keep climate change impacts as low as possible" and that adaptation "is essential because impacts cannot be avoided." Both approaches offer alternatives.

The article provides the example of "mitigation to reduce changes in precipitation patterns that would affect agriculture versus adaptive development of crop varieties resilient to a wider range of precipitation." More efficient, less expensive air conditioners could serve as both a mitigation and adaptation strategy by reducing electricity consumption for space cooling, especially if the electricity is produced by burning fossil fuels, and by making the appliances more affordable for lower-income consumers.

Impacts on the energy sector

In the past two years, Wilbanks led a team in assessing the effects of climate change on U.S. energy consumption, production and supply. The work was supported by the Department of Energy as a part of a series of reports by the U.S. Climate Change Science Program about climate change science. Reporting analyses that demand for interior cooling will rise 5-20% per 1°C increase in average temperatures and that demand for interior warming will fall 3-15% per 1°C rise in warming, the assessment emphasized that implications would vary by season and region, and that impacts would reflect differences in energy sources as well as total energy needs. Because electric fans and air conditioning deliver cooling, the team projected "increased demands for electricity, which is likely to affect planning by the electric utility industry."

In regions with more severe climate change, energy production could be especially vulnerable to severe storms and water shortages. Hurricanes, expected to become more intense as oceans warm, can disrupt offshore oil and gas production. Hydroelectric power and nuclear power plant cooling require abundant water supplies that could be threatened by an annual reduction of snowfall in the Western mountains and episodic water shortages such as those currently plaguing the South and Midwest. Energy sector planners "have time available to consider strategies for adaptation to reduce possible negative impacts and take advantage of possible positive impacts," Wilbanks says. "The energy sector can incorporate climate change as an aspect of uncertainty and risk in longer-term strategic planning and investment."

Impacts on communities

As a part of the Climate Change Science Program and with support from the U.S. Environmental Protection Agency, Wilbanks led another team considering possible impacts of climate change on cities and smaller communities. As with the energy sector, the study addressed the future sustainability of human systems in terms of vulnerabilities and risks. Under this approach, the research attempts to grapple with the societal impacts of climate change. The categories included population size and distribution, as well as ways in which sustained climate change might affect economic and technological institutions.

As with ecosystems, the study suggests that vulnerabilities of cities and communities may vary widely according to a variety of characteristics, including location. Cities in coastal areas subject to severe storms and sea-level rise would experience challenges distinctly different from those in population centers in arid areas more vulnerable to water scarcity and fires. "While the potential for adaptation by American cities and developed nations to reduce their vulnerabilities is considerable, potentials for some densely populated cities of Asia and Africa are not as bright," Wilbanks says.

Resilience

An important new effort to understand and enhance the preparation of communities for environmental threats is the Community and Regional Resilience Initiative. The program is an outgrowth of the Southeast Regional Research Initiative, supported by the Department of Homeland Security and led by ORNL. The Laboratory's role is not an accident.

"Oak Ridge is recognized nationally and internationally as a leader in conducting research on responses to climate change in collaboration with teams at other institutions," Wilbanks notes. Capitalizing on this reputation, ORNL helps cities think through the complicated issues that accompany emergency response plans on a large scale. As the program matures, Laboratory officials hope that years of studying climate and its impacts will translate into the ability to help communities adapt to what could be some of the most dramatic changes of the 21st century.—*C.K.*

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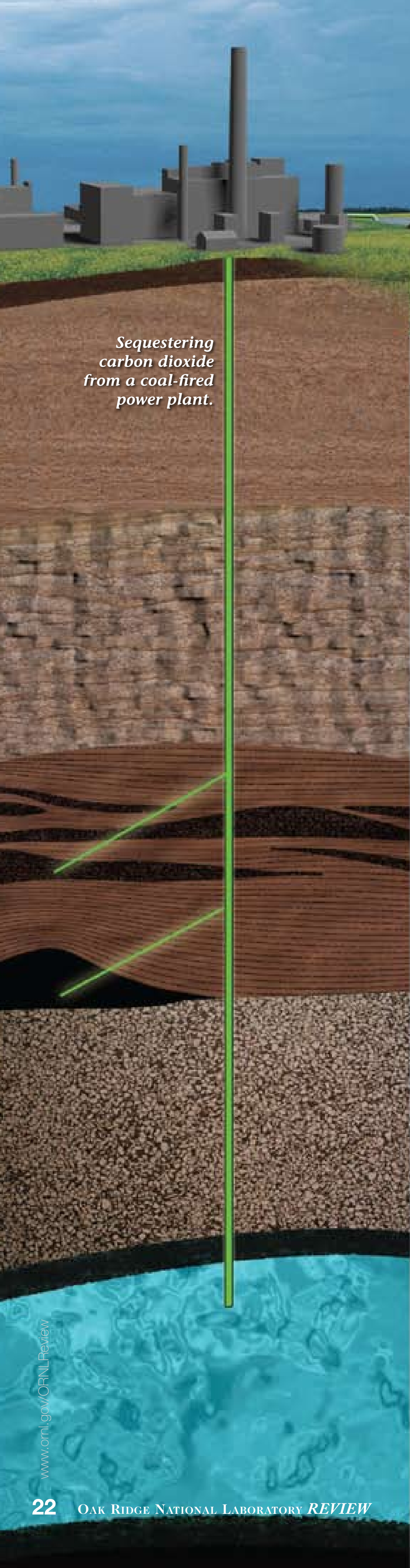

Sequestering carbon dioxide from a coal-fired power plant.

REVERSING THE TREND

Researchers seek creative ways to slow the buildup of atmospheric carbon dioxide.

In March 2007 a Reuters reporter telephoned Gregg Marland with this comment and question: "China is growing rapidly. When will China's carbon dioxide emissions catch up to U.S. emissions, which currently are number one in the world?"

Marland, a climate researcher at Oak Ridge National Laboratory, expressed interest in the question and promised to get back to the reporter. He had read reports that China was building an average of one new coal-fired power plant every week.

"I did a rough extrapolation and discovered, much to my astonishment, that CO_2 emissions in China will likely surpass U.S. emissions in 2007," Marland says. In March Reuters reported the finding, which was carried by most of the international media. The following month the International Energy Agency, which uses a carbon emission estimation methodology Marland helped develop, reached the same conclusion, reshaping the climate debate.

Sources and sinks

CO_2 emissions do not observe political boundaries. Recognizing this fact, one strategy that could have a global impact on the CO_2 buildup in the atmosphere is mitigation, broadly defined as efforts to reduce the sources and enhance the sinks of greenhouse gases.

Improving the energy efficiency of buildings and producing electricity using nuclear, wind and solar energy instead of fossil fuels will reduce CO_2 emissions. ORNL Corporate Fellow David Greene, a lead author for the "Transport" chapter of the mitigation report of the Intergovernmental Panel on Climate Change's fourth assessment, says that reducing CO_2 emissions from transportation "will almost certainly require a transition to more electric drive vehicles, whether powered by hydrogen fuel cells or electricity from the grid." Although increased use of more-fuel-efficient vehicles, cleaner diesel vehicles, hybrid cars and biofuels would slow the growth of CO_2 emissions from the developed world's highway vehicles, the accelerating motorization of the developing world—especially China, India and Southeast Asia—will likely produce a net increase in the world's CO_2 emissions from motor vehicles through 2030.

ORNL's Rod Judkins leads a project designed to assess the ability of inorganic membranes and activated carbons to capture CO_2 before the gas is emitted from coal-fueled power plants. Dave Cole is participating with the Bureau of Economic Geology of the University of Texas at Austin in the Department of Energy's Frio Brine Experiment. The researchers study the ability of an underground brine-saturated, sandstone formation in Texas to sequester injected CO_2 in a well 5700 feet (1737 meters) deep.

The first ORNL report on the process of storing carbon in the earth was a 1980 technical memorandum entitled *The Collection, Disposal and Storage of Carbon Dioxide*. "We proposed injecting CO_2 into the ocean, the soil and depleted oil and gas fields," recalls Marland.

In 1977, when Marland collaborated with Freeman Dyson at the Institute for Energy Analysis in Oak Ridge, Alvin Weinberg, IEA director and former ORNL director, asked Dyson "to think great thoughts." Dyson proposed planting lots of trees to remove CO_2 from the air. "Freeman was one of the pioneers of carbon capture and storage," recalls Marland, who later advocated tree planting. "I have twice testified before Congress on the importance of trees as a way to capture and store carbon, " says Marland, author of one of the first chapters on land use change and forestry for the International Panel on Climate Change and a contributor to chapters for the panel's first three assessments.

Marland recently commented that dark forests absorb more light than grassy fields and snowy surfaces. The observation suggests that mature trees planted close together—which absorb less carbon dioxide than growing trees—might warm, rather than cool, the planet in some locations.

Carbon in soil

Cultivation and harvesting of crops and deforestation lead to the loss of about half of the carbon stored in these soils to the atmosphere. Oak Ridge scientists are examining ways to increase soil carbon storage to slow the buildup of atmospheric CO_2.

In March and July 2007, researchers collected soil cores containing grass roots a yard deep from a 40-acre switchgrass field in Milan, about 300 miles west of Oak Ridge. Switchgrass is a potential feedstock for producing cellulosic ethanol as a renewable, carbon-neutral, transportation fuel.

The experimental plot, administered by the University of Tennessee, is being used for a study of soil carbon storage by researchers from Oak Ridge, Argonne and Pacific Northwest national laboratories and several universities. ORNL's Robin Graham leads the project, called Carbon Sequestration in Terrestrial Ecosystems, which was initiated in 1999 by DOE's Office of Science.

"We had a multidisciplinary crew of about 20 microbiologists, plant ecologists, modelers and an economist collecting soil cores containing roots of different cultivars, or varieties, of switchgrass," Graham says. "The work in March was our first field event to get baseline information on a bioenergy crop.

"One of our tasks is to determine the carbon content of each soil core after weighing it and the separated roots. We analyze the roots and remaining soil samples for carbon and nitrogen content using an elemental analyzer that combusts the carbon and nitrogen in the samples to form gases we then measure."

The researchers seek to answer a variety of questions. Do different switchgrass cultivars vary in terms of root structure and chemistry, aboveground biomass and the influence of root morphology on soil and soil carbon? Do microbial communities change with switchgrass root structure and depth and affect soil carbon content? Does the root mass vary at different depths?

To learn how to optimize long-term storage of carbon in soil, researchers are planning to study the effect of amendments to the soil on soil carbon content in the switchgrass field. One carbon-containing fertilizer of particular interest is black char, powdery charcoal that can enhance soil's retention of carbon.

"In the Amazon some of the soil is dark, rich and productive," Graham says. "That productivity may be due to human manipulations a thousand years ago. People there may have started fires for cooking, tilled the resultant char into the ground and learned this practice increases soil productivity. We intend to amend some soil with black char and study the resultant effects on soil processes that control carbon sequestration."

Wilfred Post, Tony King and others use high-performance computing to model the roles of microbes in decomposing organic matter and forming mineral-humus structures involved in physically protecting soil carbon from decomposition. Soil contains three times as much carbon as vegetation. Soil carbon turnover time ranges from a few years to thousands of years, depending upon the soil's physical and chemical properties, temperature and moisture.

Humans and the carbon cycle

Tristam West has compiled and analyzed extensive data from hundreds of field experiments, primarily in the United States, Canada and Europe, which compare carbon releases and soil carbon storage associated with conventional plow tillage versus no-till agriculture. Using a no-till approach, farmers disrupt the soil less, typically reduce decomposition rates and increase soil carbon.

"Scientists speculated that these effects would occur but had no proof until they conducted experiments and analyzed data," West says. "The result indicated that soil carbon increases with no till, quantifying and confirming a near-term greenhouse gas mitigation strategy that works. In addition to the benefits of lower carbon emissions and less erosion, farmers who use no-till agriculture also experience reduced fuel costs."

One concern is that no-till farmers must increase use of herbicides to destroy the weeds normally killed by plowing. But, West says, monitoring of chemical accumulations in groundwater and waterways and on land has thus far revealed no adverse environmental effects of increased herbicide usage.

How humans influence the carbon cycle continues to intrigue Gregg Marland. He and his colleagues have calculated the CO_2 produced by tractors and trucks, by the manufacture of fertilizers and pesticides and by all the elements of managing farms and forests. "Humans affect the global carbon cycle not only through the carbon in plants and soils, but also through all of the activities involved in managing the production and harvesting of crops," he says.

Noting that the world's population has tripled within his lifetime, Marland makes this telling comment: "Humans have been intimately involved in perturbing the carbon cycle. We are now confronted with trying to minimize the impact."—*C.K.*

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THOM MASON

Newly minted Oak Ridge National Laboratory Director Thom Mason has been breaking lots of ground at ORNL. He joined the Laboratory in 1998 as scientific director of the Spallation Neutron Source with construction of the $1.4 billion science project just beginning and moved through the ranks to become director of the project in 2001. His leadership contributed to the completion of the SNS on time and on budget. With neutrons now flying for research, Mason has been named ORNL director, replacing Jeff Wadsworth following his departure to Battelle's Columbus, Ohio, headquarters.

At 42, Mason is the youngest director appointed to the position since the late Herman Postma and represents a new generation of leadership at ORNL. His new role comes at a time of transition as the Laboratory shifts from a period of construction and modernization to an increased focus on utilizing new facilities to deliver premier scientific research. With an investment in high-performance computing that will result in the world's most powerful open-science supercomputer, the SNS, a rejuvenated campus, the upgraded High Flux Isotope Reactor and the new Nanoscience Center, Mason's job will be to guide the Laboratory quite literally from big construction to big science.

In an interview with the *ORNL Review*, Mason talks about this transition and his own hopes for his tenure here.—*L.B.*

With the SNS construction and HFIR upgrade complete, with ORNL on track to have the world's most powerful supercomputer and a mad flurry of other construction now nearly done, your job as lab director contains an increasing responsibility to take these facilities and deliver the science. How do you plan to do that?

Mason: Over the past several years, the agenda for the Laboratory has been the development of a variety of new capabilities. That came about partly because of funding opportunities, but the strategy also resulted from a genuine need. A number of areas had been neglected for too long and required a renewed focus of attention. That activity is ongoing. There are still older areas of the Laboratory that need modernization. I think what we see shifting is the balance between new facilities and capabilities and the execution of the science program using the new assets we now have. Our staff and customers have high expectations, given the investments that have been made, that we are going to be delivering first-ranked science. We must meet those expectations.

Most of these new facilities contain scientific capabilities that cut across traditional disciplines at the Laboratory. Part of our challenge is understanding that our potential is not restricted to any single discipline or programmatic outcome. We must view the new capabilities as tools and ask the question, "How can we use those tools in different ways?" (Former ORNL Director) Jeff Wadsworth likes to talk about nano-info-bio as the underlying science, so one of the things I'm interested in doing is thinking about and engaging in a discussion of how we take nano-info-bio as a toolkit and apply the tools in a creative way to today's problems, such as energy.

You mentioned energy. What do you see as the primary areas of research focus for the Laboratory over the next five to 10 years?

Mason: Energy is one of the pressing societal problems that we are applying our capabilities to solve—one of what we sometimes call "grand scientific challenges." This emphasis comes partly from the fact that ORNL is an energy lab, but also because there is a realization that solutions for adequate and affordable energy will require some historic breakthroughs in science. At our new Bioenergy Science Center, for example, there is considerable excitement about developing cellosic ethanol to displace foreign oil imports and to provide a sustainable source of non-fossil fuel. While the anticipation is great, some fundamental science needs to be done if cellulosic ethanol is actually going to become economically viable. This is basic science driven by a desired outcome.

I think another area that is going to be evolving in the near future is nuclear technology. My own view is that the increased use of nuclear has to be part of the long-term energy solution, but there are still challenges to be resolved. I think ORNL can have an impact on, for example, what to do with the waste stream, which is important if there is going to be headroom for nuclear power as an option for electricity production. Fortunately, ORNL has a rich history and a broad suite of capabilities in nuclear research.

Finally, I think we have a stewardship responsibility for these new, major facilities that we need to execute well on behalf of the external science community. A big part of this responsibility is making sure we have scientific programs at ORNL that are preeminent among the users of those facilities. We would be squandering the opportunity if these users do not enrich our science base and vice versa.

This issue of the *ORNL Review* is devoted to climate change. What is ORNL's potential in this area of research?

Mason: Climate is obviously becoming increasingly important. There is a lot of policy discussion taking place about mitigation and legislation being introduced that needs to be informed by the very best science. If we look, for example, at what is happening with high-performance computing and the impact of tremendous improvements in computer performance on what we can model, we have an opportunity to impact the climate discussion. This is going to be important for public understanding, because people do not experience the climate, they experience weather. When someone sees a newspaper article that says the average temperature will increase by 3 degrees, it is easy to say, "Well, yesterday it was 95 and today it's 85. That's a 10-degree change, so who cares about a 3-degree change?" The reason you care about a 3-degree change is that when the average changes that much, there are changes in the weather that do impact us. The rainfall patterns may shift, storm frequency and severity may change and so forth. We need to understand these changes and their impacts. So the high-performance computing, along with our experimental work in environmental and biological science, give us the ability to understand the impacts of climate changes. Research at ORNL allows the scientific community to make better contact between these significant shifts in average climate behavior and things that actually have an impact on people and populations—and therefore on the policies that deal with these changes.

Becoming lab director seems like a transition for you as well, shifting from the start-up of a large project to oversight of a number of programs in various stages of life. How are you approaching this transition?

Mason: Well, it's funny, because I was originally attracted to Oak Ridge, not so much by the opportunity to be involved in a construction project but because of the opportunity that was going to be available after the construction project. I never expected that I would be responsible for the construction of SNS. As Laboratory director, my interest comes more from executing the science phase than the building phase. Now you don't get to execute the science if you are not building and going forward. If we are not kicking off some things now that will come to fruition in five, 10 and 15 years, then those opportunities will never happen. I come from this point of view: here are the things we want to be doing. In order to do them there is some amount of building that we have to do but building is not an end in itself. You have to build in order to be able to do the science at the other end.

AVOIDING THE DARK

A visualization tool can predict a hurricane's impact on the Southeast's electric grid.

The next time a violent hurricane slams the Southeast's shores, the Federal Energy Management Agency may learn more quickly than in the past which transmission lines are likely to be knocked out and which counties face a major power outage. Using Oak Ridge National Laboratory's new "situational awareness tool," government agencies in conjunction with electric utilities can expedite a coordinated federal emergency response to areas most likely to need assistance immediately after a hurricane or tornado batters a southeastern region.

"Major power outages in the United States over the past decade have a recurring theme—the lack of wide-area situational understanding," says Tom King, manager of electric transmission and distribution technologies for ORNL's Energy Efficiency and Renewable Energy Program. "Knowing the electric grid's vulnerabilities and ways to protect the infrastructure will enable utilities to prevent some large-area blackouts and help the government prepare for and more quickly respond to destructive events."

ORNL has developed a computer-driven, situational awareness visualization tool for monitoring and visualizing in real time the status of the Southeast's transmission system. The tool also can predict the transmission lines particularly at risk of storm damage as well as the population in specific areas likely to lose power as a result of destructive winds.

This real-time national visualization tool, called Visualizing Energy Resources Dynamically on Earth (VERDE), is being developed for the Department of Energy's Office of Electricity Delivery and Energy Reliability. With access to the world's most powerful open supercomputer, ORNL is leading the development of a national visualization capability to enable electric utility control-room personnel to see potential and actual problems affecting electric grids across the Eastern Interconnection, which covers the region east of the Rocky Mountains, and the Western Interconnection, which embraces the region west of the Rockies.

"Our team used novel computational approaches supported by a network of sensors, real-time visualization, graph algorithms and hybrid simulation to enable a more secure and reliable electric grid," says Arjun Shankar who, along with John Stovall, is leading the ORNL effort.

Using Google Earth as its platform as well as population density data from ORNL's Landscan, VERDE will assist federal agencies in the coordinated response to power outages, natural disasters and other catastrophic events. VERDE will eventually provide emergency responders and decision makers with instant information on the real-time status and health of the electric grid and critical energy sectors. VERDE can assist in preventing wide-scale power outages by helping utilities improve their understanding of the electric grid status with neighboring regions and across a wider region.

Additionally, with the data and analysis available to electric utilities and government entities, faster restoration and coordination of relief efforts are expected to be improved. According to King, functions featured in VERDE will include a determination of the real-time status of the electric grid; real-time weather data; data on transmission-line power flows and voltages for certain transmission lines and the on-off status of motors and generators; and the ability to do extreme contingency analysis, to improve the accuracy of predictions that knocking out a particular set of transmission lines or power generators could make a wide-area blackout more likely.

ORNL is developing this strategic tool in collaboration with industry, other national laboratories and university partners. Tennessee Valley Authority played an important role in collecting utility data for the Southeast visualization tool. TVA and other major utilities spanning multiple regions across both grid interconnections are providing information on the real-time status of their systems. Analysis generated by DOE's Visualization and Modeling Working group is also being incorporated into the tool to visualize predictive impacts of hurricanes on the electric delivery infrastructure.

Genscape and other businesses are providing ORNL's computational creations with additional datasets to improve visualization and advanced modeling analyses, lessening the likelihood that electric utility operators and their customers will be in the dark.—C.K.

6 R&D 100 Awards

Researchers at Oak Ridge National Laboratory have received six R&D 100 awards, given annually by R&D *magazine to the year's most technologically significant new products. ORNL led all other Department of Energy national labs in number of awards received in 2007 and remains the leading all-time winner among DOE labs with 134. ORNL researchers (in bold) were recognized for the following inventions, all but one of which were funded by DOE:*

- ***Piranha***, developed by **Mark Elmore, Brian Klump, Robert Patton, Thomas Potok, Joel Reed** and **Jim Treadwell.** The Piranha knowledge discovery engine uses intelligent agent technology and a very large cluster computer to analyze large volumes of text data with unprecedented speed and accuracy. Piranha sorts huge numbers of text documents into groups that are easily processed by people. The system can find similar documents to a document of interest; remove duplicated documents, such as identical news stories from different sources, and automatically classify documents by topic. Because of the scalability of the agent architecture and better algorithms, Piranha runs 100 times faster than other search engines and can work with continuously changing data sets. The U.S. military and the Department of Homeland Security are among the users of Piranha to analyze large sets of streaming data.
- ***Pharos Neutron Detector System***, developed by **Richard Riedel, Ronald Cooper** and **Lloyd Clonts**. Pharos is a small, low-power, neutron detection system that can be used to identify nuclear materials at airports and harbors. Pharos can determine the direction and distance from which neutrons come, allowing the system to track targets after they have been identified. The system's advantages include large-area detector coverage, extremely low power requirements and digital communication capability.
- ***Cast Nickel Aluminide for Improved Productivity of Steel Heat-Treating Furnaces***, developed by Duraloy Technologies, Mittal Steel USA, Anthony Martocci (consultant), **Vinod Sikka, Michael Santella** and **Jeffrey McNabb**. Cast nickel aluminide has a unique combination of high-temperature strength and oxidation resistance, which is critical for continuous operation of steel plate heat-treating furnaces. The nickel aluminide eliminates the need for frequent furnace shutdowns, greatly reducing energy use, carbon dioxide emissions and costs.
- ***High-Performance LMO-enabled, High Temperature Superconducting Wires***, developed by SuperPower Inc., **Parans Paranthaman, Tolga Aytug** and **Amit Goyal**. This high-current, second-generation superconducting wire with a lanthanum manganate buffer exhibits the unique combination of strength, flexibility, fabricability, throughput and low cost needed for power-grid applications, including coils and motors. The wire set three world records for superconducting in 2006. As replacements for copper power cables, ORNL-SuperPower cables will carry more electricity much more efficiently and can be retrofitted to the standard grid infrastructure.
- ***Large Area Imager for Standoff Detection***, developed by Lawrence Livermore National Laboratory, Space Sciences Laboratory at the University of California at Berkeley, **Lorenzo Fabris, Thomas Karnowski** and **Klaus-Peter Ziock**. The Large Area Imager is a search instrument that can find radiation sources within a 100-meter swath while traveling at 40 kilometers per hour. Compared with other instruments, the device locates radiation sources 25 times faster with unprecedented sensitivity to weak sources. The Department of Homeland Security funded this project.
- ***Armstrong Process CP Ti and Ti Alloy Powder and Products***, developed by International Titanium Powder, **Craig Blue, Jim Kiggans, Stephen Nunn, Phil Sklad, William Peter, John Rivard, Art Clemons**, BAE Systems, AMETEK, National Energy Technology Laboratory and Red Devil Brakes. The Armstrong Process is a new method of producing titanium powder that reduces costs significantly. Titanium's strength, low mass and corrosion resistance make the metallic element ideal for many manufacturing uses, but titanium is prohibitively costly because of the difficulty and expense of extracting the metal from ore. Some believe this process extracts titanium from ore much more cheaply than conventional methods, making the metal feasible in many new applications. This process—which can produce titanium continuously, unlike other methods—is the most significant development in the titanium industry in 50 years.

...and the WINNERS are...

Accomplishments of Distinction at Oak Ridge National Laboratory

Stephen E. Nagler and **Richard J. Norby** were named ***UT-Battelle Corporate Fellows*** in 2007, the highest level of recognition for career achievements in science and technology leadership at Oak Ridge National Laboratory. **Nagler**, chief of ORNL's neutron scattering scientists, is internationally known as a leader in probing magnetic excitations and quantum critical behavior in materials. **Norby**, science team leader for experimental ecology, is a pioneer in large-scale manipulative field experiments, including one in which he demonstrated the importance of root and soil processes in mediating tree responses to elevated atmospheric carbon dioxide.

UT-Battelle Corporate Fellow **Steve Zinkle** received the ***IEEE Nuclear and Plasma Sciences Society's 2006 Fusion Technology Award*** and the ***American Nuclear Society's 2007 Mishima Award*** and was elected a ***fellow of the American Nuclear Society*** for his pioneering contributions to the understanding of radiation effects in structural materials for fission and fusion energy systems.

Eugene P. Wigner Fellow **Peter Maksymovych** received the ***Nottingham Prize*** for his thesis-based presentation, "Non-local Hot Electron Surface Chemistry in Scanning Tunneling Microscope."

ORNL researchers who developed **Hybrid Solar Lighting** earned the ***Excellence in Technology Transfer Award*** from the ***Federal Laboratory Consortium for Technology Transfer.*** Winners include **David Beshears, Melissa Lapsa, Art Clemons, Dennis Earl, John Jordan, Randall Lind, Curt Maxey, Jeff Muhs, Christina Ward** and **Wes Wysor**.

Thomas Thundat has been selected by *Nanotech Briefs* magazine to receive a ***Nano 50 Award***, recognizing that his nanomechanical cantilever sensor technology for physical, chemical and biological detection, is one of the "top 50 technologies, products, and innovations that significantly impacted, or is expected to impact, the state of the art in nanotechnology."

An ORNL-developed technology titled "Nanocomposites via Epitaxial, 3-D Self-Assembly of Nanodots of One Complex Material within Another" has been named one of the ***top 25 MICRO/NANO technologies*** by *MICRO/NANO Newsletter*. Key contributors to the technology are **Amit Goyal**, **Sung-Hun Wee, Karren More, Claudia Cantoni, Yuri Zuev, Yanfei Gao, Jianxin Zhong** and **Malcolm Stocks**.

Xiaoguang Zhang and **Thomas Schulthess** shared in an inaugural award presented to **William H. Butler**, formerly of ORNL, by Japan's National Institute for Materials Science. Butler, director of the University of Alabama's Center for Materials for Information Technology, the two ORNL scientists and a Tulane University researcher received the ***NIMS Award for Recent Breakthroughs in Materials Science and Technology*** for research expected to lead to smaller, better and cheaper computer hard drives.

ORNL has been accepted into the ***Environmental Protection Agency's National Performance Track Program*** in recognition of the Laboratory's outstanding environmental compliance record.

Stephen Nagler

Richard Norby

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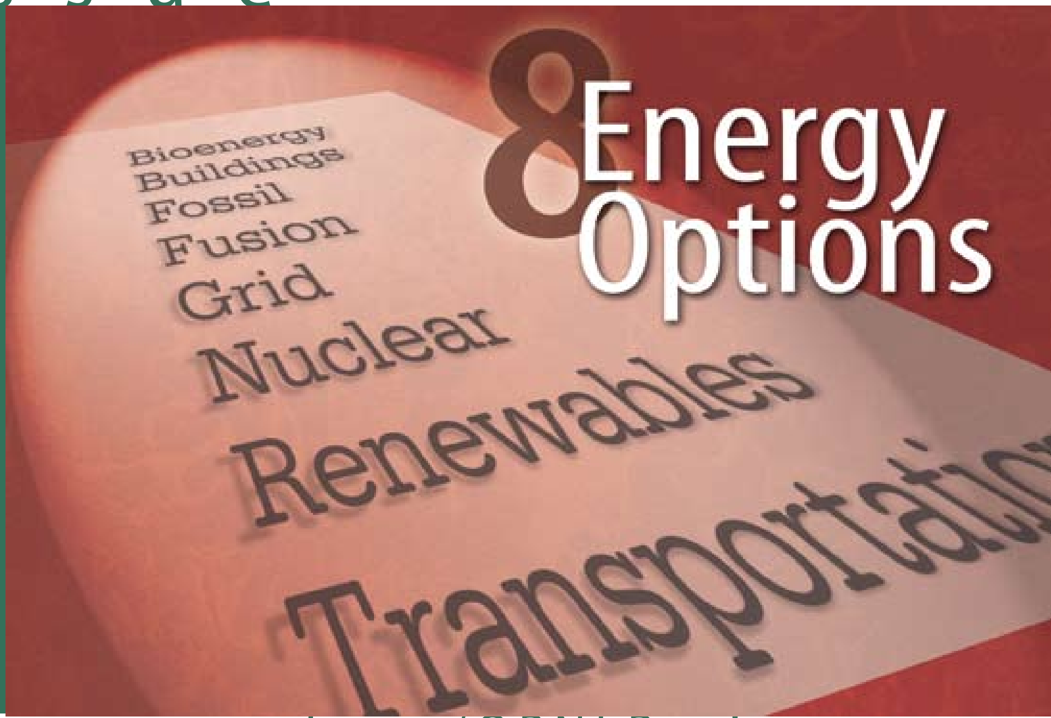

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Life underground:

- ORNL researchers are looking to microbes to learn how ecosystems store and process carbon

Summer school:

- Each year, the Oak Ridge Reservation serves as a learning center for students and teachers on summer break studying everything from salamanders to water bugs. See article and slideshow

More to say:

- Read additional comments from "A Closer View" interview with new Laboratory Director Thom Mason

Slideshow:

- See additional images of researchers and experiments related to stories in the *Review*

Reference desk:

- Read relevant papers on climate change

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