Oak Ridge National Laboratory

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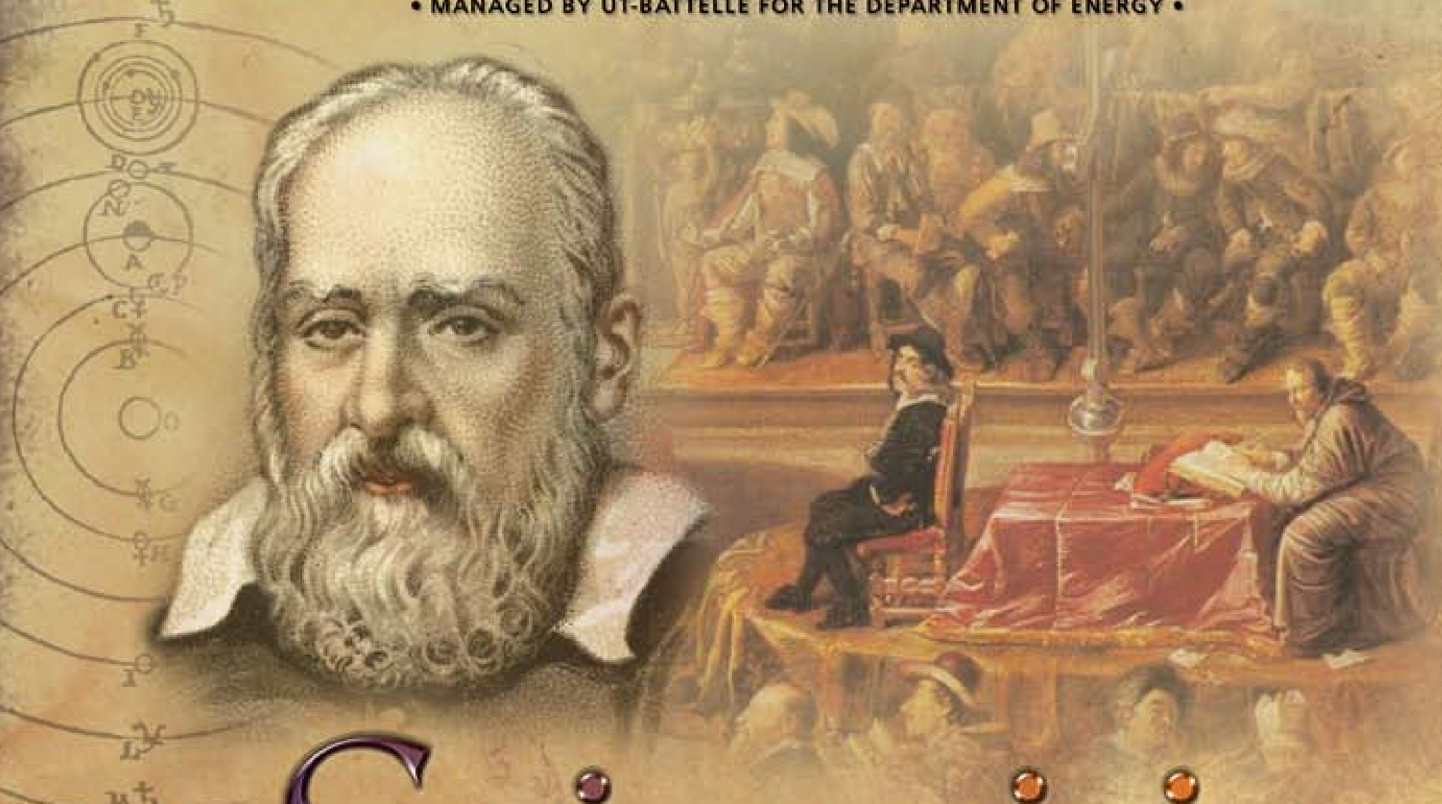

Scientific Myths

Ethanol's Choices

Recycling Nuclear Fuel

Oak Ridge National Laboratory
REVIEW
• MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY •
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Challenging Scientific Myths

One of the most fascinating aspects of human behavior is the readiness of millions of people to believe with absolute certainty in ideas that have no basis in fact. Referred to by a variety of labels, depending upon their relative importance, these beliefs are unrelated to theological faith described by Christian doctrine as "the evidence of things not seen." Over time, they take the form of popular myths spread almost exclusively through word of mouth, often from generation to generation.

Many such myths are harmless, such as the belief that yawning is contagious, or that water in the southern hemisphere spins in reverse going down the drain. Unfortunately, the scientific community is confronted with another category of myths that on occasion can have far greater consequences for important public policy decisions. Perhaps the most famous collision of science and myth occurred in 1633, when Italian astronomer Galileo was interrogated for 18 days by the Papal Inquisition, incensed by his claim that Earth was not the center of the universe. Disregarding his scientific data proving that Earth actually revolved around the sun, the court put Galileo under house arrest until his death in 1642.

This issue of the *ORNL Review* is dedicated to research taking place at Oak Ridge National Laboratory that hopefully will change public attitudes about a number of contemporary scientific myths. Articles about some of these myths, such as the undependable nature of wireless technology or the notion that only a person with a high degree of technological sophistication can operate a zero-energy house, are relatively light in nature and serve simply to help readers understand an interesting topic.

The implications of other myths are more serious. Over the past year, for example, a chorus of international criticism has challenged the environmental and economic benefits of biofuels, frequently without regard to the Department of Energy's investments in a new generation of biofuels that would require greatly reduced amounts of water, fertilizer and land needed for food crops. Likewise, pervasive myths about spent nuclear fuel, and the relationship of those myths to the expansion of nuclear power, might in time be reshaped by a greater understanding of new reprocessing technologies.

The *Review* does not suggest that these issues should now be closed. In fact, each topic would benefit from a spirited debate in which all parties relied, not upon popular myths, but rather on a rigorous collection of data applied to the highest standards of scientific review. Scientific myths are formed over a long time, and only through a sustained process of honest discussion can we hope to change them.

In the case of Galileo, the Church formally accepted his theory in 1983, exactly 350 years after his trial. One can only hope that other myths will not be so enduring.

Billy Stair

Billy Stair
Director, Communications and External Relations Directorate

News & Notes

Children from grades K-12 at the dedication of the new Oak Ridge High School

Striving for the best

More than 1,200 corporate leaders, elected officials and citizens attended dedication ceremonies in August for the newly renovated Oak Ridge High School. The $61 million renovation was the largest K-12 construction project in Tennessee history. The $17 million raised privately was also a Tennessee record. The high school renovation was coordinated in part by UT-Battelle, which donated $2 million to help leverage support for a one-half cent sales tax referendum that received approval from 73% of Oak Ridge voters.

The new high school facility offers students some of the nation's most sophisticated science laboratories, a priority of the renovation project. Equipped with geothermal heat pumps and an array of other energy-efficient technologies, the school serves appropriately as a daily laboratory in a city that is home to one of the world's leading energy research facilities.

UT-Battelle views the high school project as both an example of corporate citizenship and part of a long-term strategy to attract talented researchers to Oak Ridge National Laboratory. ORNL Director Thom Mason, who chairs the Oak Ridge Public Schools Education Foundation, sees parallels in the modernization of the school and modernization at the Laboratory. In both instances, Mason believes that investments in modernization will provide lasting returns in the form of gifted researchers and their families who will see in Oak Ridge a commitment to the highest standards of science and education.

New S&T park at ORNL

Groundbreaking ceremonies in August for the first building to be constructed at the new Oak Ridge Science and Technology Park symbolize the Laboratory's latest effort to partner with private companies. Located on 40 acres adjacent to the main ORNL campus, the S&T park will be the first private business park to be built within the boundaries of a Department of Energy national laboratory.

The park's first facility will house the National Security Engineering Center of Professional Project Services Inc., or Pro2Serve. The $14 million headquarters will include space for privately employed scientists and engineers with expertise in quality assurance, national security, and environmental, safety and health issues.

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"Greening" the ORNL campus

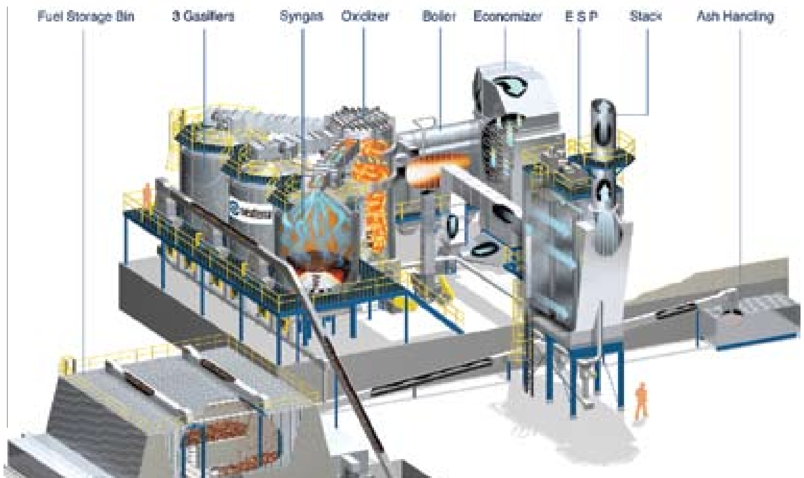
Since the 1950s, most buildings on ORNL's main campus have been heated or cooled by the centrally located steam plant. To produce steam, the plant has long burned fossil fuels—initially coal and then natural gas and heating oil. ORNL will soon switch to biofuel in the form of wood chips. This transition will produce steam while reducing spiraling energy costs and unwanted carbon dioxide emissions.

The Department of Energy has signed an $89 million energy saving service contract with Johnson Controls, based in Milwaukee, Wisconsin, to upgrade ORNL's antiquated steam plant. Under the contract, the energy savings of $8.7 million annually over the next 18 years will go to Johnson Controls to pay for the work. After 18 years, the savings will go toward reducing ORNL's fuel consumption bills.

DOE has mandated a reduction of energy consumption by 30% and water consumption by 16% at its facilities by October 2009. At ORNL, the new system and other improvements are expected to reduce energy consumption by 50%, water usage by 23% and fossil fuel consumption by more than 80%. The resulting slowdown in the buildup of atmospheric carbon dioxide is the equivalent of pulling 2.1 million cars off the road.

Johnson Controls' major project at ORNL involves refurbishing the old steam plant so that it can heat and gasify wood chips. The hot gas driven from the biofuel will heat water to make steam.

ORNL will contract with area biomass suppliers to obtain waste wood products from within a 50-mile radius of the Laboratory. Waste wood might be refuse from pallet manufacturers and tree bark from timber mills. Johnson Controls will build a structure near the steam plant to dry the delivered wood chips.



The refurbished steam plant will be fueled by wood chips instead of natural gas and heating oil.

Less water will be used largely because the long steam line from the steam plant to the High Flux Isotope Reactor and other buildings in Melton Valley will be eliminated. A new structure will be built in this complex to house a new Cleaver Brook super boiler that will supply steam to the buildings nearby.

The Laboratory is once again tapping another renewable energy resource—sunlight—to power Building 3147 where research on energy-efficient technologies for buildings is conducted. In August, Lightwave Solar Electric of Nashville began installation of a 288-ft.-long by 10-ft.-wide array of solar collectors made by SunPower. The solar cells convert 18.7% of sunlight's energy into electricity, generating more than 50 kilowatts at peak power. By comparison, the array of solar cells near ORNL's visitor center operates at 13% efficiency.

Making America more competitive

Approximately 250 leaders of America's research community convened in August at Oak Ridge National Laboratory for the National Science and Technology Summit to suggest ways to strengthen economic competitiveness. Sponsored by the White House Office of Science and Technology Policy, the summit was a requirement of the America COMPETES Act of 2007.

The attendees represented senior research officials of the government, universities, industry and national laboratories. The panels offered recommendations for increasing government's research investments, enhancing the return on these investments and enlarging the pool of American scientists and engineers through improvements in science, technology and math education.

Three members of the Tennessee congressional delegation—Sen. Lamar Alexander, Rep. Bart Gordon and Rep. Zach Wamp—urged the research and education community to encourage elected officials to support sustained investments in science and technology. Alexander said that "the best way to stop sending billions of dollars overseas for oil to countries that don't much like us is to keep our brainpower advantage."

One recommendation that reflected this advice called for stable funding for large research facilities to avoid multiyear project delays and optimize research output. Another recommendation supported making permanent the R&D tax credit for industry.

continued from S&T park

Company executives say Pro2Serve plans to employ 300 people at the new facility, slated for completion in November 2009.

Some $3 million was invested in site preparation and installation of energy, water and communication services. Of this investment in the park's infrastructure, $1.8 million came from federal and state grants.

Myth: Ethanol forces a choice between food and fuel

Reality: A new generation of cellulosic ethanol will not require a reduction of the food supply

One of the most contentious policy arguments in the energy debate is captured by a 2008 cover story in *Time* magazine that asks rhetorically whether ethanol is a "clean energy scam" that forces a Catch-22 choice between growing crops for food or for liquid fuel as an alternative to imported oil. The article's indictment of biofuels included, in addition to world food shortages and higher food prices, an equally alarming contribution to environmental degradation.

The story produced a passionate rebuttal from many researchers who insist that little real competition exists between food and energy crops and that, in fact, a new generation of biofuels actually has the potential to lower food prices, minimize water pollution, and prevent deforestation. Lost at times in the high-volume debate is the ability to distinguish between valid concerns and alarmist criticisms that see in biofuels a simple explanation for complex problems. The reality, according to Oak Ridge National Laboratory analysts, is that biofuels are potentially one answer to the energy challenge if they can be developed economically and sustainably.

"Plant-based biofuels can help combat global warming without damaging our environment if we make the right choices," says Reinhold Mann, ORNL's associate laboratory director for biological and environmental sciences.

First-generation ethanol, the kind often blamed for food shortages, is produced from starchy grains, such as corn, in the United States and Europe and from sugarcane in Brazil. Mann says the next generation of ethanol is likely to be developed from a variety of nonfood crops rich in cellulose, the complex carbohydrates made of sugar units that form cell walls in stalks, trunks, stems and leaves of most plants.

Cellulosic ethanol has the potential for dramatically changing the biofuels debate. Because much of the feedstock for cellulosic ethanol can be grown on marginal land, expanded use of biofuels would not require choosing between growing food or fuel crops on fertile land. And because several cellulosic sources are perennial crops that demand little water and no fertilizer, their environmental impact is far less than that of annual crops like corn. Researchers with the Department of Energy's new Bioenergy Science Center at ORNL are confident that cellulosic ethanol ultimately can provide more energy than corn ethanol or gasoline. In approximately five years, commercially viable technology may be able to unlock sugars economically from cellulose and ferment them to produce a new generation of ethanol that will not require a choice between food and fuel.

The International Energy Agency predicts that global demand for energy will grow by more than 50% by 2030. The financial and environmental costs of foreign oil and rising greenhouse-gas levels motivated Congress to enact the Energy Independence and Security Act of 2007, which established a renewable fuels standard that starts with domestic production of 9 billion gallons per year in 2008 and increases to 36 billion gallons per year by 2022. Any hope of reaching these ambitious goals will require cellulose-busting technologies that take advantage of America's 1.3 billion tons of biomass (see sidebar, "Myth: America Does Not Have Enough Biomass").

Food, carbon and deforestation

The myths surrounding biofuels are many, including the notion that the growth of biofuel crops in America sets in motion a process that leads to deforestation in the Amazon. The logic asserts that when Kansas farmers use existing cropland for fuel feedstock instead of food, the resulting increase in world food prices encourages Brazilian farmers to expand food production by clear-cutting the jungle and burning native vegetation, with a commensurate increase in carbon emissions.

Keith Kline, a project manager at ORNL working on social and environmental challenges in developing nations, says, "Several recent studies document the large environmental impacts of forest clearing. If biofuel plantations were responsible for this indirect land use change, then biofuels would appear to cause more greenhouse gas emissions than the oil they displace. The argument—'An acre removed from food production in America is offset by a new acre cleared in Brazil'—is persuasive because of its simplicity and apparent common sense. In reality, the processes driving deforestation are much more complex."

Kline points to an analysis released in 2001 of the findings of 152 case studies that explored the factors that resulted in tropical deforestation. "The major finding was that there was no single cause," Kline says. Rather, interactions among cultural, technological, biophysical, political, economic and demographic forces drive the process.

In another study, the U.S. Department of Agriculture (USDA) calculated that global food prices rose 43% between April 2007 and April 2008. ORNL landscape ecologist Virginia Dale, a corporate fellow who studies causes and effects of land-use changes, points out that according to a USDA calculation, biofuels accounted for only 3% to 4% of the cost increase. Far more responsible for rising food prices was the cost of energy associated with fertilizing, harvesting and transporting crops. Other factors included poor harvests caused by heavy rains and drought, export restrictions and, perhaps most significantly, increased demands for food in developing nations as populations grow and standards of living rise.

Dale and Kline work with ORNL colleagues Russell Lee, a geographer who analyzes environmental and energy plans, and Paul Leiby, an economist who evaluates the effects of public policies on alternative fuels and energy security. The group makes a variety of data available to policymakers.

Other pioneering work at ORNL in the area of biofuels is being conducted by Corporate Fellow David Greene, who analyzes the economics of renewable transportation fuels, and by climate researcher John Drake, who uses one of the world's most powerful supercomputers to simulate the impact of biofuel crops on climate change.

Research at ORNL suggests the argument that a biofuel boom will require the cultivation of forested land and grassland rests on the inaccurate assumption that additional land is unavailable for food production. Dale contends the amount of land needed to raise crops for biofuels is on the order of 20 million hectares worldwide, a relatively small portion compared with the 6 billion hectares of non-forested land recently identified by the United Nations Food and Agriculture Organization as suited for rain-fed agriculture. In Tennessee, for example, at least 400,000 hectares of marginal land are available for biofeedstock such as switchgrass.

"The amount of existing cleared and underutilized land is far greater than what is needed to produce food crops and biofuels," Kline says. "Increasing production does not necessarily require more land. U.S. agricultural output has grown consistently using less and less land. Meanwhile tropical agricultural frontiers lack incentives for proper soil management, and extensive areas are allowed to burn repeatedly."

Year after year around the world, Kline says, hundreds of millions of hectares of forests burn. "The growing demand for biofuels, with incentives for sustainable production, could create opportunities to recuperate degraded land, improve rural welfare and reduce annual emissions rather than cause more deforestation. Providing tenure and incentives for stable production reduces pressure to clear more forests."

Kline notes that Brazil plans to document the sustainability of sugarcane for biofuels, aiming to improve productivity while minimizing downstream environmental impacts. The Swedish firm SEKAB recently signed a contract with the Brazilian government to produce ethanol through an environmentally sustainable process. The criteria prohibit forest clearing and call for a reduction in carbon dioxide emissions by at least 85% of those from fossil fuel combustion.

The technological challenge

All of these arguments in support of cellulosic biofuel are predicated on the basic question: "Will it work?" Developing consolidated bioprocessing technologies that produce ethanol by using microbial enzymes to free and ferment sugars from cellulose is one of the grand scientific challenges of the 21st century. Some liken the task to turning your coffee table into a liquid you can pour into your gas tank.

Switchgrass in Tennessee

Myth: America does not have enough biomass to displace gasoline

Reality: U.S. lands can produce the ethanol to displace one-third of petroleum

Biofuels produced from biomass, such as cellulosic ethanol, could replace perhaps as much as a third of the current U.S. demand for transportation fuels with a homegrown, renewable energy source without affecting food production," according to Department of Energy Under Secretary for Science Raymond Orbach.

Technology challenges aside, some critics question whether America realistically has enough biomass to meet such an ambitious goal. A landmark study led by ORNL Senior Research Economist Bob Perlack and funded by DOE's Office of Energy Efficiency and Renewable Energy sought for the first time to estimate whether America has sufficient biomass to provide needed power, fuels and products.

"We looked at using agricultural residues from major grain crops and the use of some of this land for growing dedicated energy crops, such as switchgrass, poplar and willow," Perlack explains. "In conducting our resource assessment we conditioned all of our estimates subject first to meeting projected demands for food, feed, export and fiber."

Published in 2005, the Billion Ton Study concluded America has approximately 1.3 billion tons of biomass, enough to displace 30% of transportation petroleum with biofuels. Skyrocketing global oil prices and accelerated corn-based ethanol production since then have motivated an update, forthcoming this fall. The new report will assess economics and policies in addition to resources and focus on 2007-2030, as contrasted with the long-term period (2025-2050) probed in the original study.—*Dawn Levy*

The current state of the technology shows that certain enzymes can digest cellulose, but at present are too expensive and inefficient for commercial production of cellulosic ethanol, says microbiologist Martin Keller, director of ORNL's Biosciences Division.

To make transformational breakthroughs that will enable commercially viable biofuel production on a national scale with minimal environmental impact, the Department of Energy has established three multi-disciplinary, multi-institutional bioenergy research centers—led by ORNL, by the University of Wisconsin-Madison in partnership with Michigan State University and by DOE's Lawrence Berkeley National Laboratory. Between 2007 and 2012, each center will receive $135 million to improve understanding of systems biology and transmit solutions to industry.

The Oak Ridge-led team is focusing on tackling the fundamental problem of biomass recalcitrance, or the resistance of cell walls to deconstruction. Mann says the center's strength is the breadth of the research team assembled, which includes, in addition to ORNL experts, leaders in plant science from the University of Georgia, the Noble Foundation in Oklahoma, and the University of Tennessee.

Given that ethanol is an emerging industrial sector with both established and start-up companies, the ORNL team addresses questions that their industrial partners, which include Verenium, Mascoma and Arborgen, are unlikely to explore: What does the biosynthesis of cell walls look like and what factors influence it? Why are some plants more easily degradable than others? Which enzyme is most effective at breaking down sugars in each cell wall so they can be fermented into alcohols? How can natural systems, such as microbial communities, most efficiently accomplish cellulose degradation? Can a single enzyme be designed to degrade cellulose and ferment sugars in one step? Answering each question represents a fundamental step toward making biofuels economically and environmentally viable.

"These questions represent a big lever that we're working on," Mann says. "If we can move that lever, we will have tremendous impact on the ability to get the sugars out of the biomass for fermentation into ethanol and other products. Because petroleum is a feedstock for many products, the ORNL-led team has a large opportunity if we get the biomass production right in a sustainable way to go beyond just transportation fuels and use biomass as a feedstock for other value-added chemicals, such as possibly plastics, solvents, lubricants, adhesives, pharmaceuticals, cosmetics and building materials." Mann cites the 2007 opening by DuPont and corn refiner Tate & Lyle of a nearby facility in Loudon, Tennessee, that manufactures the biomaterial 1,3 propanediol (PDO™), which uses corn instead of petroleum as the raw material. Bio-PDO™ is now available for carpeting, textiles and de-icing fluids.

At ORNL, the primary feedstock candidates for cellulosic ethanol are switchgrass, a drought-resistant native grass that takes about three years to establish and that can be harvested annually for a decade before reseeding, and poplar trees, a short-rotation woody crop that can mature to harvest in seven to ten years.

"We are focusing on switchgrass and poplar trees because they are two genuine bioenergy crops, not just model systems," Mann says. "We use them as paradigm crops. The knowledge derived from those two crops would be applicable to other cellulosic feedstock."

Keller, director of the Oak Ridge– led Bioenergy Science Center, says breakthroughs in automation have emerged less than a year after the center opened. "These advances would not have happened without the collaboration of experts from different disciplines," he adds. "For the first time in the history of biofuels research, the new centers founded by DOE have provided the opportunity to integrate research across many different disciplines—microbiology, plant biology, supercomputing, mass spectrometry, chemistry—and work together on this common goal. The multidisciplinary approach of our partners will enable the breakthroughs we need in this field."

Keller's colleagues are attacking the recalcitrance problem from two perspectives. While some researchers investigate new microorganisms and enzymes, others seek to engineer the cell walls of plants to make them easier to digest.

One project explores extremophiles, microorganisms that thrive in environments that would kill most life forms. The researchers went to Yellowstone National Park to collect microorganisms that live in hot springs and digest cellulose from trees that fall into the scalding water. The scientists now have about 40 cultures growing at ORNL that subsist only on switchgrass and poplar trees. Another novel technology under investigation is gasification of cellulose to produce "syngas," a mixture of hydrogen and carbon monoxide that can be chemically catalyzed to make biofuel, Keller says.

If scientists find microorganisms that can convert biomass to ethanol efficiently, Keller believes industrial implementation of solutions will quickly follow. On the other hand, if solutions entail re-engineering some green plants, the process may take a decade as researchers try to identify or modify a gene that can overcome recalcitrance, engineer the gene to express itself in plants, obtain enough seed to scale up ethanol production, conduct field trials and get approval from the Environmental Protection Agency. "Humankind took 100 years to get into the problem we are facing now with oil," Keller says. "Finding the solution will not happen overnight."

Keller's guarded optimism in some respects reflects the current thinking about the future and potential of biofuels. A new generation of biofuels based on inedible green plants could be a sustainable and affordable alternative to imported oil that does not require a moral choice between food and fuel. Nevertheless, supplying humankind with sufficient food and energy remains one of the critical challenges of the 21st century.—*Dawn Levy*

Image opposite page: Gathering microbes for biofuels research at Yellowstone National Park

Myth: Alzheimer's is an incurable disease

Reality: Computer simulations indicate new drugs may reverse the course of the disease

Few diseases are as emotionally painful, both for the victims and for their families, as Alzheimer's. The anguish of watching the gradual deterioration of a loved one's mental faculties for decades is accompanied by the harsh realization that the process is irreversible. Against this backdrop of despair, recent simulations from one of the world's most powerful supercomputers provide cause for hope.

For the majority of people diagnosed with Alzheimer's, the degenerative brain ailment is a deadly two-protein disease. Amyloid protein lurking outside neurons, the fundamental units of the body's nervous system, forms plaques. Tau protein, loitering inside neurons, forms neurofibrillary tangles. At present, drugs delay symptoms but ultimately do not halt formation of plaques and tangles. Tomorrow's drugs, however, may turn into a medical myth the prevailing view that Alzheimer's disease is unstoppable.

In 2007 ORNL researchers Edward Uberbacher and Phil LoCascio used 100,000 processor hours on the Laboratory's Cray XT4 Jaguar supercomputer to investigate the mechanisms by which a new class of drugs acts. The drugs, called caprospinols, may stop the growth of Alzheimer's fibrils and even disassemble the threadlike fibers.

"This is the first time that molecular dynamics have been used to simulate the mechanisms these drugs use to interact with and reduce the growth of Alzheimer's fibrils," says Uberbacher, who leads a joint ORNL-University of Tennessee team. "We learned that these drugs work several different ways, and the findings gave us new ideas about how to improve the drugs."

Uberbacher, LoCascio and colleagues used a software code called LAMMPS to develop a computational simulation of the interactions of different drugs with Alzheimer's fibrils. "This simulation is very much like an experiment," Uberbacher says. "The simulation shows us lots of different possible drug interactions with the fibril at once."

The researchers used the information to explore mechanisms by which drugs attach to and reconfigure small proteins called peptides bound in fibrils, which aggregate in the Alzheimer's brain as plaques. The buildup of proteins may cause loss of neurons and vascular damage, leading to degeneration of the brain.

Prior to running the simulation, the scientists mathematically represented the chemical bonds within the drugs and fibrils, which set the parameters for possible types of molecular interactions.

"Because we can perform quantum-mechanical, ab initio calculations on one thousand or so atoms, we can generate this knowledge in a way that is more accurate and useful than what pharmaceutical companies usually produce," explains LoCascio. "Hopefully this method will become more widespread in industry and lead to better drug design."

During the simulation, the ORNL researchers used the supercomputer to perform molecular mechanics calculations to predict each drug's activity. Drug molecules interacted with the protein molecules of the fibrils, but they also interacted with each other.

Results show promise. Some drug molecules were found to bind to the growing ends of Alzheimer's fibrils, impeding further growth. A drug developed by researchers at Georgetown University and licensed by Samaritan Pharmaceuticals prevented an Alzheimer's peptide from changing to a conformation that would allow addition of peptides to a growing fibril. Another drug unraveled tangled fibrils by causing their peptides to dissociate.

Collaborators at the University of Tennessee are conducting laboratory experiments to evaluate promising compounds in mouse brains. UT researchers have developed specialized micro-CT and MRI technologies for imaging Alzheimer's plaques in the brains of small animals. In addition, UT hosts a transgenic colony of mice engineered to harbor a gene associated with human Alzheimer's disease.

The specialized brain imaging and genetically unique animals at UT and supercomputer simulations at Department of Energy facilities have improved understanding of how drugs act on fibrils. The insight paves the way for rational design of new drugs, Uberbacher says.

"The simulations performed on Jaguar are an important demonstration of a new paradigm for dynamic modeling of drug–protein interactions," Uberbacher says. "As a bonus, the collaboration is a model for how DOE computing facilities can interact with medical universities."

Researchers believe the awesome power of the world's largest computers may be what is needed to break the hold that Alzheimer's disease has on elderly populations.

—Dawn Levy

Myth: ORNL glows in the dark

Reality: The Laboratory has removed decades of legacy waste

The scene is all too familiar. At tailgate parties or church socials, when strangers meet Oak Ridge National Laboratory employees, they invariably seek a cheap laugh with the question: "Do you glow in the dark?"

Unfortunately, for more than five decades, the annoying joke was grounded at least to some degree in fact. In the Laboratory's early years, workers' relative inexperience with radioactive fuels and wastes, combined with the urgency of the Manhattan Project and later the Cold War, produced legacy contamination that has shaped the image of both ORNL and the surrounding Oak Ridge community. Like many such images—some parts fact and many parts fiction—the contamination was never as broad in scope as some suggested. Still, once the "glow in the dark" myth took hold of the public imagination, only a prolonged effort to remove legacy contamination held any hope of creating a more favorable image for the Laboratory.

Today a glow surrounds the ORNL campus, but radioactivity is not the source. Instead, what many view as a "green luminescence" is the result of construction of 1.2 million square feet of new energy-efficient buildings and, equally important, the removal of more than 1,000 tons of decades-old legacy waste.

Since 2000, the Laboratory's managing contractor, UT-Battelle, has been committed to transforming ORNL into a modern, clean and attractive place to conduct world-class research. The task has been enormous. Getting rid of waste—some radioactive and some just accumulated trash— is in many ways as important as providing new buildings. Not only does the job entail a sustained commitment of overhead funds, but also much of the material requires special handling to ensure the safety of workers onsite and off.

In 2000 the average age of ORNL facilities was more than 40 years, with a large number in various states of disrepair. Laboratories in older parts of the campus housed hundreds of containers with unlabeled materials left behind by departing researchers. Before the materials could be removed, staff from the Environmental Management Programs had to perform the tedious tasks of identifying and characterizing the contents of each container. Every item was checked for potentially hazardous radiation levels. Because some buildings contained cancer-causing asbestos, disposal required special handling governed by strict guidelines.

Against the backdrop of an aging infrastructure filled with tons of legacy materials, UT-Battelle embarked upon an accelerated modernization plan that included, in addition to the construction of new facilities, an aggressive effort to reverse five decades of neglect. To undertake such a monumental challenge without direct federal appropriations, UT-Battelle imposed an internal "legacy tax" to collect about $2 million annually for the Legacy Material Disposition Initiative. The unprecedented commitment of funds was driven by years of previous neglect and the problem that some buildings were literally falling down.

UT-Battelle to date has allocated $25 million in internal funds to remove legacy wastes and unneeded chemicals and materials from more than 30 excess facilities. "We have hauled off 30 tractor trailer loads of radioactive materials, two tractor trailers loaded with 17,238 indi-

vidual chemicals and more than 1,100 gallons of contaminated oils," says Martin Tull of ORNL's Environmental Management Programs office. "We have also recycled 5,200 tons of metal, cardboard, paper and other material. And we hauled off 4,560 pumps and motors—and that does not cover everything by any means."

As the Laboratory sought to get rid of legacy waste, a parallel effort was under way to move ORNL staff from nearly 2 million square feet of outdated and expensive facilities, and into nearly 1 million square feet of new facilities that boast high energy efficiency and state-of-the-art technology. The project included the demolition of 70 excess buildings and the consolidation of 10 nuclear facilities into four. Using a highly unique combination of federal, state and private funds, the Laboratory from 2002 to 2007 opened 13 new facilities at a combined cost of approximately $1.8 billion. Parking lots and outmoded buildings were replaced with 181,000 square feet of modern laboratories and 1,409 new offices.

Six of ORNL's new buildings have achieved LEED (Leadership in Energy and Environmental Design) certification. LEED criteria were developed by the U.S. Green Buildings Council, a building industry coalition that promotes environmentally responsible technologies.

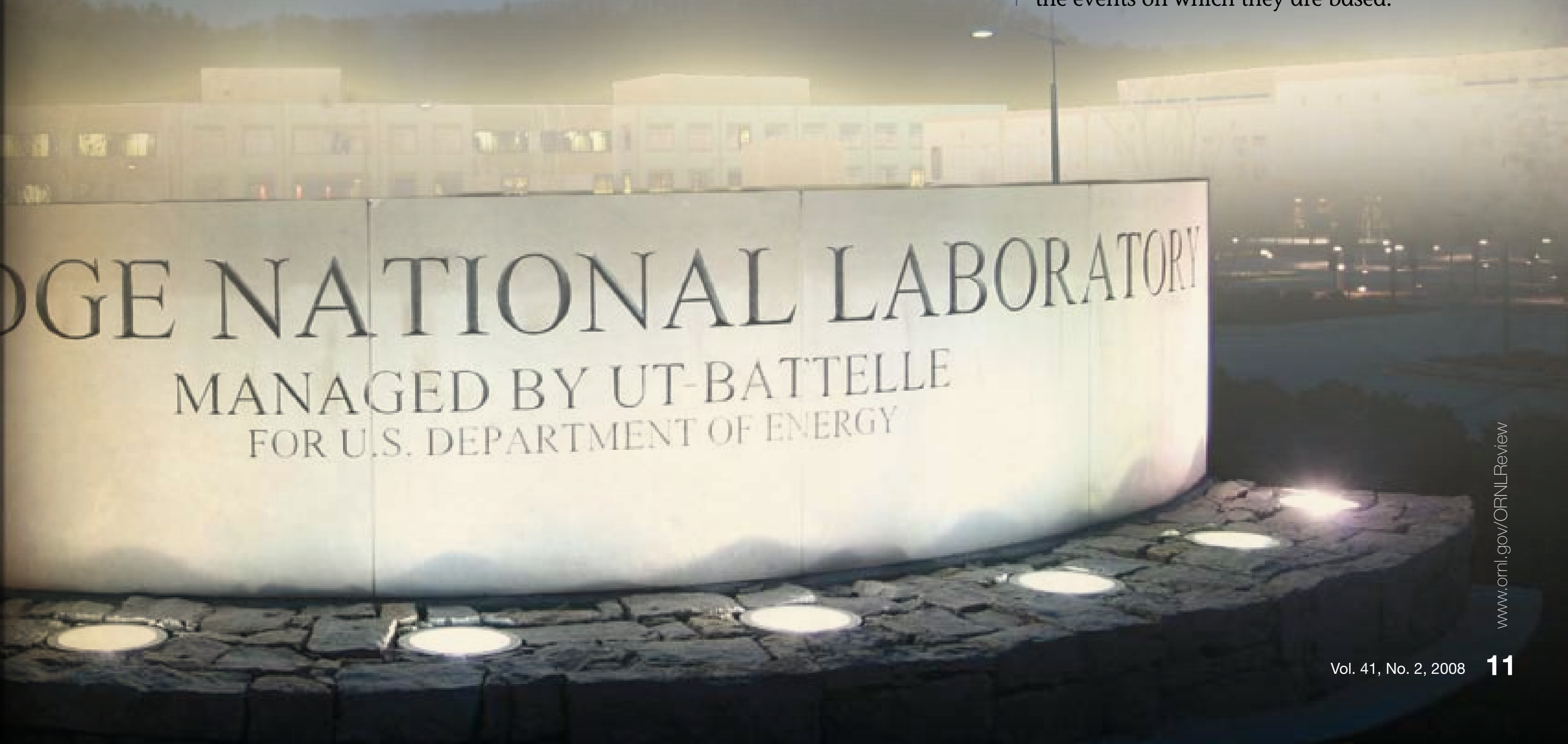
The reduced environmental impact has also been impressive. More than 30 million gallons of once-through reactor cooling water have been diverted from ORNL's waste treatment system, and discharges of mercury into White Oak Creek have been reduced by nearly 80%. Other upgrades are paying off in vastly reduced water consumption, improved fire protection, a better sanitary and storm sewer system and improved telecommunications. By 2010, Johnson Controls, Inc. under contract with the Department of Energy will have refurbished ORNL's central steam plant so that its source of heat to make steam for heating and cooling most ORNL buildings will be chips of waste wood, not expensive natural gas and heating oil. ORNL's fossil fuel requirements will decrease by 80%, reducing its fuel costs by 30% and carbon dioxide emissions by 730,000 tons, equivalent to taking about 2 million cars off the road.

The outside world has taken note of ORNL's environmental initiatives. In January, ORNL received the DOE Office of Science Noteworthy Practice Award for Sustainable Building Design & Construction, followed in June by two DOE Star Awards for Pollution Prevention. In November, the Environmental Protection Agency recognized ORNL with the WasteWise Gold Achievement Award for Integrated Sustainability.

Ironically, ORNL's enormous progress in addressing the Laboratory's environmental legacy has led some to the mistaken belief that the job is done. In fact, UT-Battelle is working closely with DOE and the state of Tennessee on a project called the Integrated Facilities Disposition Project that seeks to complete the cleanup effort in Oak Ridge. The IFDP would remove from the Oak Ridge Reservation the remaining legacies of the Manhattan Project and Cold War, including materials containing more than 27 million curies of radioactivity, 5.4 million square feet of excess facilities and 10 million cubic yards of contaminated soil and groundwater.

The dilemma of perception remains. Seeking to eliminate a decades-old image of environmental contamination, ORNL in the past six years has perhaps made more progress than any other laboratory in the DOE system to remove legacy wastes and replace outdated facilities. On one hand, ORNL staff would like to be recognized for their considerable progress and their work's contribution to the improved image of the Laboratory and Oak Ridge community. At the same time, they do not want their achievements to be a distraction from the task that remains.

Meanwhile, with each passing month the "glow in the dark" myth evolves increasingly into the realm of urban legend. Unfortunately, myths often linger long after the events on which they are based.



Myth: Enormous supercomputers are making research impractical

Reality:

New techniques make it possible to handle staggering amounts of data

In April 2000, when UT-Battelle assumed the management of Oak Ridge National Laboratory, ORNL's supercomputer was measured at one teraflop, a then-unimaginable one trillion floating point operations per second.

A few years later, the same machine did not rank among the world's top 500 supercomputers. In a truly international competition that includes Japan, Spain and a host of other nations investing in massive computational power for scientific research, high-performance computers have become so big so fast that among some a myth is taking hold: We have raced past the point at which researchers can practically manage such mind-boggling volumes of data generated by trillions of calculations each second.

ORNL's Jaguar system, for instance, is capable of more than 260 trillion calculations per second, making the machine (in a constantly shifting ranking) in June 2008 the fifth most powerful computer in the world and the third most powerful for open scientific research. Funded as part of the Department of Energy's Leadership Computing Facility, ORNL's Jaguar is expected to surpass one thousand trillion calculations per second, or one petaflop, by year's end. Taking advantage of what would again be the world's most powerful open computer involves challenges as daunting as designing the machine itself.

Just as the typical motorist cannot handle a racecar and the weekend pilot cannot fly an F-15 fighter jet, a researcher using a modern supercomputer is thrust into a world far beyond the desktop machine with which most of us are familiar. Producing the quality of cutting-edge science for which the machines were designed requires the ability not only to design the calculations, but also to get information in and out without compromising the system's blistering speed. Ultimately, the most important aspect of a simulation is not the supercomputer's speed, but rather the often unwieldy volume of calculation results that represents the most important aspect of a simulation.

"For most of the codes I work with, the data that comes out of the simulation tells us about the science," explains Scott Klasky, a computational physicist with DOE's National Center for Computational Sciences at ORNL. "We run a simulation, analyze the results, and from that analysis we publish the findings. In effect, we have a computational laboratory that conducts a large computational experiment, along with the associated diagnostics, analysis and visualization that lead to the major scientific insights."

Klasky is working with colleagues from Georgia Institute of Technology, Rutgers University and the Scientific Data Management Center—sponsored by DOE's Scientific Discovery through Advanced Computing (SciDAC) program—to make the basic process of getting information in and out of a supercomputer easier and more effective. Their approach is known as Adaptable I/O [input/output] System, or ADIOS, an application designed to give researchers fast, easy-to-use, portable performance.

ADIOS is an Input/Output system broken down into components. The system has simple application programming interfaces and an external XML description of the data. The system's distinct advantage lies in the fact that researchers can change the I/O implementation through the XML code and not go through the actual source code of their applications. This flexibility affords researchers the ability to move easily from one implementation to another when they switch between supercomputers or, even more important, when their I/O is not behaving properly.

With ADIOS, Klasky and his colleagues hope scientists will no longer be forced to choose between the performance of a simulation and the quality of its data output. The choice is a quandary Klasky has faced over years as a fusion researcher working with a team from DOE's Princeton Plasma Physics Laboratory. The team's Gyrokinetic Toroidal Code—simulating the dynamics of turbulence in a fusion reactor—is consistently among the most productive applications running on Jaguar. In recent runs, the code ran on 29,000 of Jaguar's 31,000 processing cores and wrote out 90 terabytes of data in two days—or the equivalent of 520 megabytes every second.

"ADIOS grew out of our pain in working with I/O and trying to produce good data from our codes," Klasky explains. "We write a tremendous amount of data. The restart data are large. We vary run to run like everyone else, but we have other data which are also used for analysis."

Data coming out of a supercomputer simulation typically fall into two general types: restart files and analysis data. A restart file is the system's version of a "save" command, writing out the state of the simulation at a given time. Supercomputers, just like home computers, are subject to unexpected burps and hiccups. Like the home computer anything that has not been saved will be lost, with one very significant difference: The loss of an hour on 30,000 processors is the equivalent of 3½ years lost on a home machine.

Data for analysis, on the other hand, contain the critical information from which a scientist may make a breakthrough. Researchers regularly find themselves having to choose between the performance of their applications and the amount and quality of the data they write. Klasky and his colleagues faced this challenge in his early years with the project.

"We found we were spending more than 20% of our computational time writing the analysis files. For scientists competing for valuable computing time, this was viewed as an unacceptable waste."

Another challenge confronting researchers is the need to include in their results sufficient metadata, or "data about the data." Including items such as labels and explanatory notes, metadata tell the researchers what they are looking at when they examine data a day, a week or even a year after the simulation

By placing the information separate from the actual source code, ADIOS makes it easier for researchers to make additions to the metadata. As Klasky explains, metadata also helps restart files do double duty, serving a useful role in analysis of a simulation.

"We want our data to be metadata-rich," Klasky explains, "with lots of annotations that can be helpful much later. For some researchers the restart file contains the state of your code, which is useful data. A lot of people write restarts and then do analysis from the restarts, so they blur the line."

In addition to ORNL, support for ADIOS comes from several SciDAC centers—including the Center for Plasma Edge Simulation, the Scientific Data Management Center and the Gyrokinetic Particle Simulation Center—and from the National Science Foundation's High End Computing University Research Activity program.

Klasky and his colleagues have tested ADIOS with a variety of the leading applications that use Jaguar, including several fusion codes, a leading combustion code,and an astrophysics code. On Chimera, an astrophysics code used to simulate core-collapse supernovas, the team was able to improve the application's performance a hundredfold with a test run using 2,048 processors.

"Chimera is one instance," Klasky notes. "In other instances the system writes out data at about the same speed as we wrote before, but adds extra annotations instead of raw binary. We now have really fast Input/Output that is going to be portable and scalable."

> ...scientists will no longer be forced to choose between the performance of a simulation and the quality of its data output

Klasky's team is working to extend ADIOS to as many systems and applications as possible. To date, they have validated ADIOS on the Cray supercomputers at ORNL and on Linux clusters. By September 2008 they expect to be applying ADIOS's unique assets to IBM Blue Gene supercomputers such as ORNL's Eugene system.

Eventually, Klasky says, they want to release the software as open source. While this goal would mean more work for the team—documentation, tutorials, bug searchers, etc.—the effort would also accelerate ADIOS development.

"We first are making sure our initial codes run on different architectures," Klasky says. "As we open up the system to more codes—and I've had lots of requests—that's when we'll get lots of error reports, and that's when people will use ADIOS differently."

Given the pace of high-performance computing, the work cannot come fast enough.—*Leo Williams*

Myth: Recycling spent nuclear fuel increases the risk of weapons proliferation

Reality: New recycling technologies can reduce the inventory of plutonium

Governments of approximately a dozen nations possess, officially or unofficially, the technology to make atomic weapons from spent nuclear fuel. As described in Tom Clancy's best-seller *The Sum of All Fears*, one of the greatest concerns of the international community is the possibility that such knowledge might fall into the hands of outlaw nations and terrorist groups seeking to make a "dirty bomb" capable of spreading radioactive contamination over large urban populations. The very real risk of weapons proliferation has contributed to a reluctance, beginning with President Jimmy Carter's decision in 1977 to halt efforts to reprocess spent nuclear fuel, to look at other options for using and storing the by-products of nuclear power.

Three decades later, concerns about global warming and the desire to reduce oil imports from politically volatile regions have led to a renewed interest in the role of carbon-free nuclear power. Researchers at Department of Energy national labs, including ORNL, are helping to facilitate the growth of nuclear power by developing new technologies that reduce the risk of proliferation and lessen the demand for permanent storage of spent fuel.

Of particular importance, ORNL research engineers are developing ways to recover and reuse valuable components of spent nuclear fuel, such as plutonium, neptunium and uranium. Their goal is to provide, for the first time, a sustainable method for managing and reusing the waste generated by the production of nuclear power. The plutonium, recycled without ever being isolated, is removed along with neptunium and some of the uranium to make a mixed-oxide fuel that is unsuitable for nuclear weapons but ready once again for fueling reactors. Simply stated, the technology repeatedly squeezes energy out of plutonium without building up an inventory of separated plutonium that could be used to build a dirty bomb.

if we decide we are going to employ recycling—extract the plutonium and then reformulate it into a fuel that goes into a reactor for transmuting—we begin down the path of making substantial reductions in the volume and availability of plutonium.

"There is no near-term solution to our energy security, climate change and economic competitiveness challenges that does not involve a concerted expansion of nuclear power," says Nuclear Technology Programs Director Sherrell Greene, who oversees ORNL's nuclear energy R&D activities. "For that expansion to become a reality, we must develop technologies for more efficiently using and reusing the uranium resource, managing the used nuclear fuel inventory, recapturing and reusing valuable constituents of used nuclear fuel and managing the waste streams."

Uranium occurs in nature, but only seven-tenths of a percent of natural uranium is fissionable U-235; the remainder is nonfissionable U-238. Plutonium is produced in nuclear reactors when U-238 absorbs neutrons from the fissioning U-235 fuel. In 1943 Oak Ridge researchers, including Enrico Fermi, demonstrated at ORNL's Graphite Reactor that plutonium could be produced in a reactor and separated from uranium and fission products. In thermal reactors, more potential fuel is created when U-238 nuclei each capture a neutron to become U-239 nuclei that then become Np-239, which then decays to turn into Pu-239. Without recycling, the inventory of plutonium would continue to accumulate in the spent fuel. Through recycling, the plutonium can be reused in mixed-oxide fuel for reactors, thus extending the fuel cycle and ultimately reducing the net inventory of plutonium.

"It's troubling to think that we can protect forever a continuously increasing inventory of spent nuclear fuel, which contains plutonium," says Dana Christensen, associate laboratory director for energy and engineering sciences at ORNL. "Rather, if we decide we are going to employ recycling—extract the plutonium

Elizabeth Walker working in a glove box and then reformulate it into a fuel that goes into a reactor for transmuting—we begin down the path of making substantial reductions in the volume and availability of plutonium. This approach would produce a corresponding reduction in the risk of nuclear arms proliferation."

The two principal fissile isotopes that provide energy for reactors and weapons are U-235 and Pu-239. In reactors, the nucleus of a heavy element splits, or fissions, into nuclei of lighter atoms, releasing neutrons and electromagnetic energy. Further fission produces light elements that nearly cover the entire periodic chart, whereas heavy transuranic elements, such as neptunium, plutonium, americium and curium result from neutron capture, not fission.

"In the reactor we make some new plutonium, but if we design and run the reactors properly, we can eventually destroy more plutonium than we make," Christensen says.

Storing what's left

With funding from DOE's Office of Nuclear Energy, ORNL scientists are working with research quantities of commercial spent nuclear fuel to develop and demonstrate new technologies for both recycling and storage.

"We are trying to develop evolutionary technologies that simultaneously reduce proliferation concerns about separated plutonium, lower the cost of production and achieve better managed waste streams," says ORNL's Jeff Binder, senior program manager for the Coupled-End-to-End (CETE) Demonstration.

At two ORNL facilities—the Irradiated Fuels Examination Laboratory and the Radiochemical Engineering Development Center—researchers strive to improve the multiple steps associated with recycling fuel rods, from their receipt and characterization to their chopping and processing. Volatile fission product species are removed, the fuel is dissolved in nitric acid and uranium, neptunium and plutonium are co-extracted and oxidized to create a solid mixed-oxide fuel pellet for powering nuclear reactors.

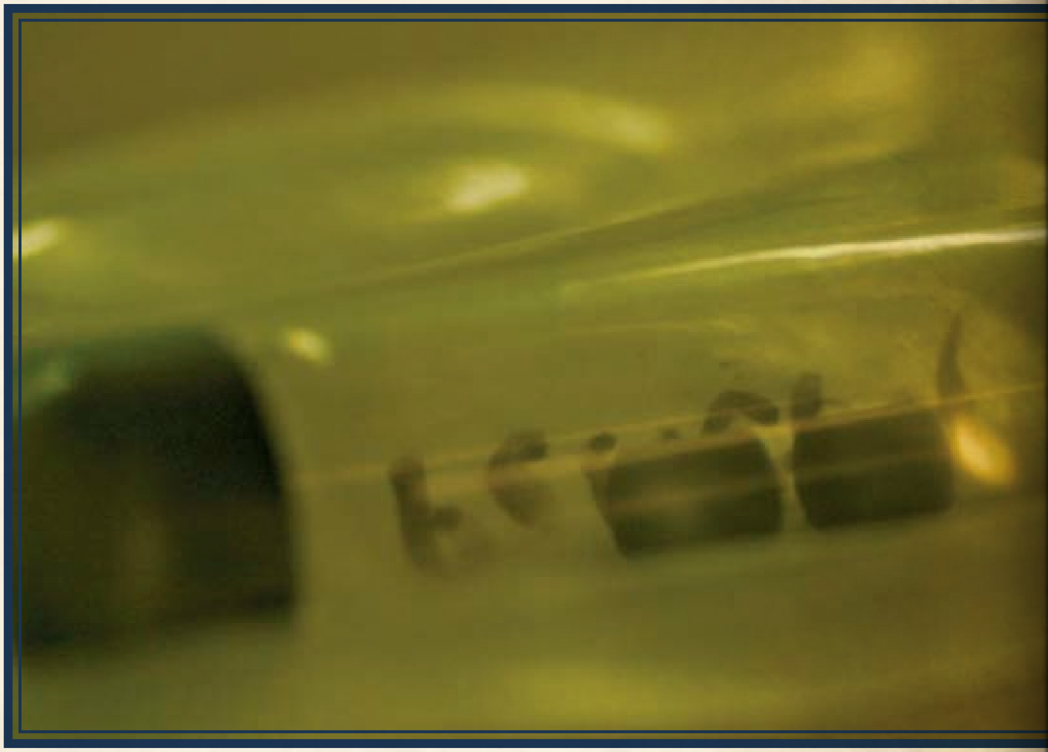
"We extract the plutonium along with the neptunium and some of the uranium so that the plutonium is never isolated," Binder says. "Co-extraction is not a bulletproof solution, but it is a step in the right direction." Neptunium provides added proliferation resistance benefits by emitting a strong, distinctive gamma ray that makes the material easier to detect if diverted. Moreover, neptunium forms Pu-238 under irradiation in the reactor. The reconstituted plutonium isotopic mix is less adaptable for weapons use.

CETE researchers are motivated by the goal of linking several recycling processes. "We don't know if the process can work on an industrial scale until we connect all of the steps together," Binder says. One immediate challenge is removal of volatile fission species prior to co-extraction. "We want to understand how to remove radioactive fission products like tritium, krypton and iodine from the fuel early in the process so they will not create problems during subsequent steps in the recycling process," Binder says.

The program also addresses the controversial issue of how best to dispose of spent fuel from commercial reactors. The Department of Energy in 1998 committed to accept spent fuel for permanent storage in Nevada's Yucca Mountain Repository, scheduled for construction in 2013. The repository's fate resides ultimately in the hands of the next president and Congress. While the debate over a permanent storage site remains unresolved, a growing volume of spent nuclear waste continues to be stored on site at the nation's nuclear power plants.

Recycling of spent nuclear fuel would fundamentally alter the nature of the debate. Changes in the characteristics of the spent fuel would reduce the net volume of waste that requires permanent storage and arguably makes storage in a repository easier and safer to manage, Binder says. Because Pu-239 has a half-life of about 24,000 years, opponents question the viability of permanent storage. "However, the long-lived isotopes could be removed, recycled and transmuted in the reactor to shorter-lived isotopes," he explains. "Instead of putting waste in a geologic repository with the need to isolate it for 10,000 years or more, we are left with the manageable problem of engineering a system designed to safely store the materials for only two to three hundred years."

Enthusiastic about these new technologies, Christensen envisions a nuclear renaissance between now and 2050.

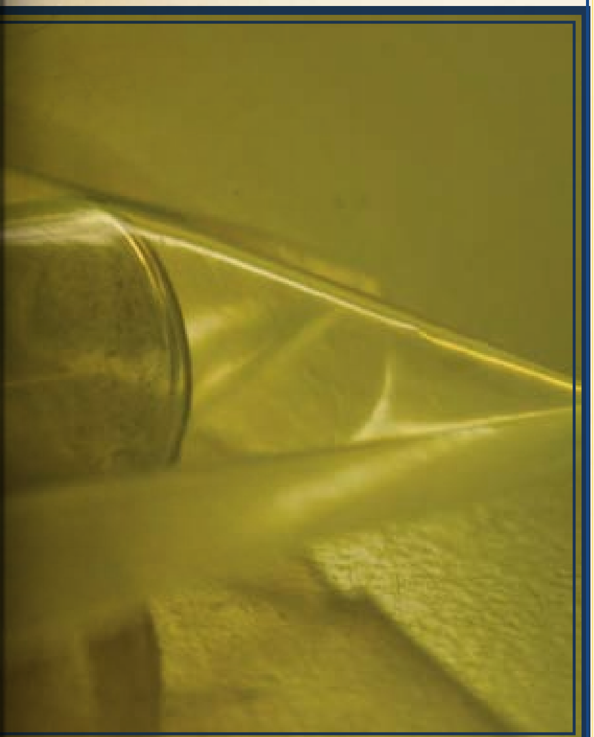


Mixed-oxide fuel pellets consist of recycled plutonium in combination with other radioactive substances.

By then, several factors should make it economically worthwhile to extract the remaining energy value of spent fuel. "We will have a huge amount of fuel value sitting in spent fuel pools," he says. "The cost of new uranium will rise, along with the cost of enriching it. At some point reusing the fuel in your pool will be cheaper than purchasing and enriching new uranium ore. To be prepared to recycle spent fuel by mid-century, we have got to be doing the research today."

Working with ORNL and Idaho National Laboratory, the technical integrator for the DOE program, are Argonne National Laboratory, whose researchers conducted some early proof-of-principle chemistry, and Los Alamos National Laboratory, where development is under way on a mixed-oxide fuel that could be used in either a thermal reactor or a fast reactor, providing flexibility in managing the resource.

Christensen sums up the opportunity and the challenge: "If we had a sustainable nuclear cycle that could recycle spent fuel into either thermal or fast-spectrum reactors, we could lower carbon emissions, enhance America's security and provide clean electricity for many decades into the future."—*Dawn Levy*



Myth: More Nuclear Power Could Eliminate the Need for Coal

Reality: Coal is likely to remain an important piece of the U.S. energy portfolio.

When Americans tap into the power grid, the large majority of our electricity comes from power plants in which coal, natural gas and nuclear fuel are burned to create steam to drive turbines. Each fuel has drawbacks. Coal is a notorious source of greenhouse gases, and though natural gas burns cleaner, it is plagued by market price volatility. Nuclear power is accompanied by concerns about cost and safety.

Alternatives are limited. Diminishing water supplies remove the option of expanding hydroelectric plants. Wind and solar are confined to niche roles—the wind is not always blowing and the sun is not always shining—while the technologies required to store and transport their energy are still over the horizon.

Largely by default, coal and nuclear fuel remain the heavy lifters of America's power grid. Per unit, nuclear fuel contains at least ten million times more usable energy than chemical fuel. That fact and the Energy Policy Act of 2005, which provided the statutory groundwork for expanding the use of nuclear power in the United States, tipped the scales in favor of a reactor-based economy. Drafting and approving the Energy Policy Act were motivated largely by the desires to abate greenhouse gases, reduce the reliance on foreign energy supplies, ensure a sustainable source of electricity and allow more rapid migration to electric transportation, says Dana Christensen of Oak Ridge National Laboratory.

Christensen sees the effort as a multi-faceted one. "It doesn't make sense to have electric cars and then recharge their batteries with electricity from coal-fired power plants unless we can also capture and sequester the carbon dioxide that comes out of the coal-fired power plant," Christensen says. "If we are going to invest in electric vehicles, which I think is the wave of the future, then we are moving toward either hybrid or all-electric vehicles. This means we must today determine how we will generate and distribute the required electricity."

Today America has about 100 gigawatts of existing nuclear capacity. "We can get to 300 gigawatts by about 2050," Christensen says. "That's a Herculean build rate of a new American reactor coming online every 60 days. We have built reactors faster than that in the past, so we know that it is possible."

Economists anticipate that electricity demand will double by 2050. Meeting this ambitious goal would require that approximately 30% of America's electricity in 2050 be derived from nuclear power, compared with 20% today. So where would the remainder of the electricity be generated?

Christensen says the math is simple. "Even with an extraordinary program of nuclear construction and a host of new energy efficiency technologies, we are still going to need coal for many, many decades to come." —*Dawn Levy*

Myth: Only an engineer can operate a zero-energy house

Reality:

ORNL's high-tech houses use low-tech operation

Jeff Christian has a mission and a vision. Over the past five years the Oak Ridge National Laboratory engineer has directed the design, construction and energy monitoring of five high-performance houses for low-income families. Aware that many people are not as "high-tech" as his colleagues at the Laboratory, Christian has also assessed the occupants' reactions to a suite of energy-efficient technologies developed by ORNL especially for the homes. Located in Lenoir City, Tennessee, and built for approximately $110,000 by Habitat for Humanity, the houses are providing the families year round with dramatically lower electric bills.

"When we started this project in 2002 in cooperation with the Tennessee Valley Authority, the cost of electricity was 7 cents a kilowatt hour," Christian says. "One of the first four houses, which were quite small, had electric bills amounting to about 50 cents a day. The local electric rate in 2008 is 9 cents a kilowatt hour. Our largest near-zero-energy house, which has 2600 sq. ft., has an electric bill of $1.16 to $1.60 per day or about $35 to $48 a month." For these working families, the annual cost savings is more than $2,000 a year.

The savings are made possible by a combination of affordable technologies. Rooftop solar panels generate electricity that can be transferred back to TVA's electric grid, occasionally making the electric meter actually spin backwards. Other special energy features include a solar water heater, a foundation geothermal heat pump installed in the excavated space as the house is being built, highly efficient appliances with Energy Star ratings, compact fluorescent lights, windows facing south toward the sun and a variety of insulation technologies inside and outside walls to keep warm air in during winter and hot air out in summer.

The goal is an affordable zero-energy home—a house that in the course of a year generates as much electricity as it consumes. And, Christian emphasizes, he wants a house with technologies that the average American can manage easily.

Christian's job involves more than planning and overseeing house construction, tweaking installed energy-saving equipment in Habitat houses and writing scientific papers on energy efficiency. He is frequently on the lecture circuit preaching the gospel about ways to use less energy in commercial and residential buildings.

"I talk to hundreds of people who are interested in the zero-energy house. Sometimes, the reaction I get is that my talk was fascinating, but the idea of building a zero-energy house sounds really complicated and a bit intimidating.

"We have had Habitat for Humanity families in homes with advanced energy technologies since 2002, and they are doing fine. They do not have any special knowledge about mechanics and electrical features beyond the average homeowner. Equally important, they do not have to pay special attention to the package of energy technologies in these homes."

Christian concedes that on occasion after a family has moved into a near-zero-energy house, he has received calls on Saturday evening about the air or water inside being too hot or too cool. He has been willing to drive to the house and do some tweaking, dialing, and switching to improve the house's performance for the safety and comfort of the family.

Despite the simplicity of operation, the houses are different from conventional houses in several ways. House 5 has a utility wall that takes advantage of appliances that release heat—such as a refrigerator and freezer—by locating them next to those that use heat to raise the temperature of air or water, such as a dryer and dishwasher. House 5 has a well-insulated basement with concrete blocks that provide thermal mass to enhance occupant comfort because the heat-storing blocks are insulated on the outside by a fiberglass drainage board and exterior finish system. Above-grade walls are 6-in.-thick structural insulated panels, which are slightly thicker than the typical 2 by 4 in. wall system of a conventional house.

Few houses have both solar panels on the roof and a foundation geothermal heat pump below ground with a compressor inside the basement. Most geothermal heat pumps for houses draw their heat from the ground after vertical wells have been dug as deep as 300 ft. Christian has found it much less expensive to install three horizontal loops made of high-density polyethylene pipes placed 5 ft. deep. The backhoe used to remove soil and rocks to provide space for the foundation can contribute to cost savings by also excavating additional space to accommodate the geothermal heat pump loops and the 200 ft.-long trenches to the sewer tap and water tap at the street.

One simple strategy is to take advantage of existing ground temperatures to supplement heating and cooling. In Tennessee, the winter temperature 5 ft. deep in undisturbed soil is as low as 45°F. In summer the soil at the same depth can be as high as 82°F. Throughout House 5's heating season from November through March, heat is drawn from the below-ground loops, causing their temperature to drop as the house warms inside. By summer, the heat in the house has migrated to the colder loops, reducing the need for air conditioning in the living space. Electric bills for cooling are thus lower.

With permission of the residents, Christian tried an experiment on House 5 during the hottest day of 2007. He wished to find out which interventions would minimize this house's effect on the Tennessee Valley Authority's critical peak period—the time between 5 and 7 p.m. when average customers use the most electricity, primarily for cooking, lighting, laundry and television. The resident stipulated a house temperature no higher than 73°F by noon.

Residents in one of ORNL's near-zero-energy houses

"Because of House 5's excellent thermal envelope with masonry inside, we were able to pre-cool the house to 71°F by noon and hold the temperature at 71°F until 5 p.m. when TVA's critical peak period begins." Christian explains. "We had programmed the thermostat to shut off the air conditioning until the cooling temperature reached 76°. The indoor air temperature drifted to 74°F as the temperature outside soared to 102°F. We continued to bring in outside fresh air, but the house temperature that day never exceeded 74.5°F."

The experiment showed that, during the hottest part of summer, occupants of House 5 can be comfortable during TVA's critical peak period without using electricity for air conditioning. Overall, the house used 0.75 kilowatt less power on the hottest day of last summer while the rooftop solar panels generated 0.75 kW. Doing without the heat pump for cooling saved 2kW, and discharging the storage batteries in the house sent 3kW to TVA's electric grid.

Christian, TVA, the Department of Energy and two building developers share a common vision. If one house can reduce TVA's peak load by 7 kW during an unusually hot day, many larger houses capable of near-zero-energy performance might cut TVA's peak power load enough to satisfy one of the agency's five-year strategic goals: to reduce demand for peak power by 1400 megawatts. A reduction of this scale would allow TVA to avoid the purchase of expensive power from other utilities or the construction of a nuclear power plant—both costly options for TVA customers.

Thanks to an increase in funding, Christian is optimistic that five new prototype houses will be built near ORNL by the end of the year. These houses would have solar panels on the rooftop, a solar water heater, a geothermal heat pump 5 ft deep, and structural insulation panels as insulation for the walls. One of the houses would have an internal utility wall called a ZEH Cor wall—steel frames containing pipes, wires and pumps to extract heat from the ground or reject excess heat in the house to the ground-source heat pump. A "feedback meter" would show the occupants the amount of electricity being used or generated. The three other houses would have different levels of energy efficiency.

This shared vision, if realized, would demonstrate further that residents without engineering degrees could live comfortably in high-tech homes.—*Carolyn Krause*

Myth: Lighter cars are less safe than heavier vehicles

Reality: New materials can make cars lighter and as safe as heavier vehicles

The driver of the racecar whizzing around the Indianapolis Motor Speedway had completed only eight laps when his car suddenly crashed into the wall. Flames burst from the car as it ricocheted from the wall, spun around and glanced off another racecar. Hushed spectators followed the accident, first with horror and then relief and amazement, as the driver walked away from the wreck, signaling that he was not hurt, just badly shaken.

Understanding why the driver was not hurt is central to debunking a common myth about the relative safety of large vehicles. The body of his racecar was constructed of carbon-fiber composites, which are one-fifth the weight of steel but just as strong and stiff. Designed to protect the driver in case of a violent collision, the car used 100% ethanol, a high-octane, clean-burning and renewable fuel that reduces air pollution and enhances racing's carbon footprint.

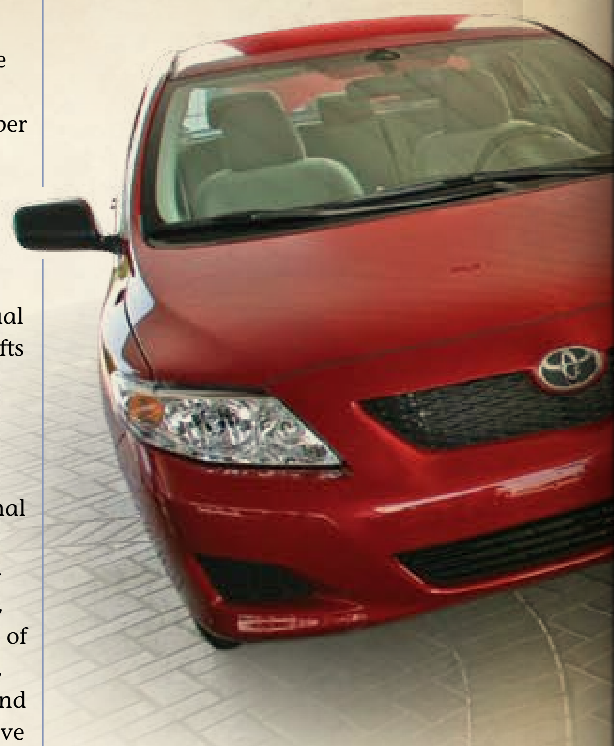
Except for extraordinary speed and limited passenger space, today's racecar provides a glimpse into the future for ordinary cars. The increasing cost of oil suggests that tomorrow's five-passenger vehicles will be smaller and lighter and will get more miles per gallon of fuel, which likely will include ethanol made from biomass. Despite the cost savings, many Americans are concerned that lighter cars represent a compromise of safety now present in heavier vehicles such as pickup trucks and sport utility vehicles.

To encourage a reduction of gasoline consumption nationwide, the U.S. government has mandated that by 2030 about 30% of the gasoline typically used for personal transportation must be replaced by a biofuel such as ethanol. The Energy Independence and Security Act of 2007 calls for an increase in corporate average fuel economy standards for cars, trucks and heavy-duty vehicles, from 27 miles per gallon to 35 mpg by 2020.

A higher percentage of lightweight cars on the road will certainly help the American auto industry achieve the higher fuel economy standard. Less certain is the impact on the 42,000 annual highway deaths if the American fleet shifts to a lower proportion of heavier vehicles made largely of conventional steel.

Since the 1990s the U.S. automobile industry has been a partner with the Department of Energy, Oak Ridge National Laboratory, other national labs, and several universities including the University of Michigan and Stanford University, in studies to determine the safety impact of lighter cars made of advanced materials, such as high-strength steel, aluminum and magnesium. The auto manufacturers have been particularly interested in carbon-fiber composites—if the cost of making carbon fiber drops to under $5 a pound—because of the composites' potential to reduce the weight of a car by more than 40% of a comparable steel vehicle's weight.

Ray Boeman, director of ORNL research at the National Transportation Research Center, is an expert on carbon composites after working for six years with Detroit automakers. He initiated the development of the Test Machine for Automotive Crashworthiness (TMAC) at Oak Ridge. TMAC quantifies the specific energy absorption of a structure in terms of the energy absorbed divided by the mass of the material crushed.



Mike Starbuck, who leads this work for the Laboratory, says that experimental and computational crash results show that steel absorbs energy by bending, folding and deforming plastically like an accordion or a crushed beverage can. In contrast, carbon-fiber composites absorb energy by many mechanisms including delamination (splitting into layers), breakage of fibers bonded to a polymer matrix and fracture of the matrix itself. In many cases composites have been shown to have higher specific energy absorption characteristics than metals.

Starbuck says researchers are working to improve vehicle design and encourage technological innovation aimed at

enhancing the safety of lighter vehicles. Boeman notes that perceptions concerning the relative safety of occupants in vehicles of different masses may be right or wrong, depending upon different scenarios.

For example, if an SUV has a head-on collision with a compact car, the occupants of the SUV may be less likely to be injured than are the occupants of the compact car. One law of physics— kinetic energy is proportional to the mass times velocity squared ($KE = mv^2/2$)—dictates that a larger vehicle has more kinetic energy than the smaller one for the same velocity. The resistance of the lighter vehicle to crash damage depends on its ability to absorb the specific energy transferred by the collision, a capability governed more by design than weight.

The situation may be different, Boeman adds, if the two vehicles driving at the same speed crash into a rigid barrier such as a large tree. The lighter vehicle would absorb much less energy than the SUV, potentially making the lightweight car safer for the occupants than is the SUV. If an automaker builds a lighter SUV, then the requirements to absorb energy decrease.

Boeman emphasizes that safer, lightweight vehicles can be designed based on another law of physics: change in kinetic energy equals average impact force multiplied by the distance traveled. The distance in this equation is the crush or crumple length designed into the vehicle. "If you have a specific amount of kinetic energy, and a certain maximum force you must stay below, the principal variable a designer can work with is crush distance," Boeman says.

Since 1978 the most common standardized test has been the frontal crash of a vehicle into a rigid barrier at 35 miles per hour. Results of crash tests and related computer simulations led to design modifications that have improved vehicle crashworthiness.

Starting in 1993 Thomas Zacharia (now an ORNL associate director of computing and computational sciences and a vice president of research at the University of Tennessee) led his group of materials and computer scientists in modifying a materials modeling code so that it could be run on an IBM supercomputer at ORNL.

One computer model used the conventional standards to predict the impacts on a car's structural materials of a frontal crash of the vehicle into a rigid barrier at 35 mph. The results of the collision simulation matched the much more expensive crash tests of vehicles and dummies instrumented with accelerometers. ORNL's simulation results were provided to the auto industry.

From 1993 to 2004 an ORNL research team developed computer models of vehicles with bodies made of composites, regular steel, high-strength steel and aluminum. With funding from DOE and the National Highway Traffic Safety Administration, the team produced detailed computer models of different vehicles after disassembling the actual cars and measuring the parts.

Each finite-element impact model divides the simulated vehicle into hundreds of tiny sections. The model includes a materials model that predicts how much energy will be absorbed and how the car body material will behave after the vehicle traveling at 35 mph collides at different angles with a rigid barrier.

The ORNL group also performed a computational analysis of a concept car made of high-strength steel, which is thinner, lighter and stronger than regular steel. The simulation indicated that lighter, high-strength steel vehicles should hold up in a crash even better than an equivalent vehicle made of regular steel. The group also found that the predicted results of a head-on collision and frontal-side collision involving a heavy vehicle and a light one varied.

As domestic and international automakers race to design and produce fuel-efficient vehicles, ORNL will play an important role in ensuring that a new generation of lightweight vehicles will not come at the expense of safety.

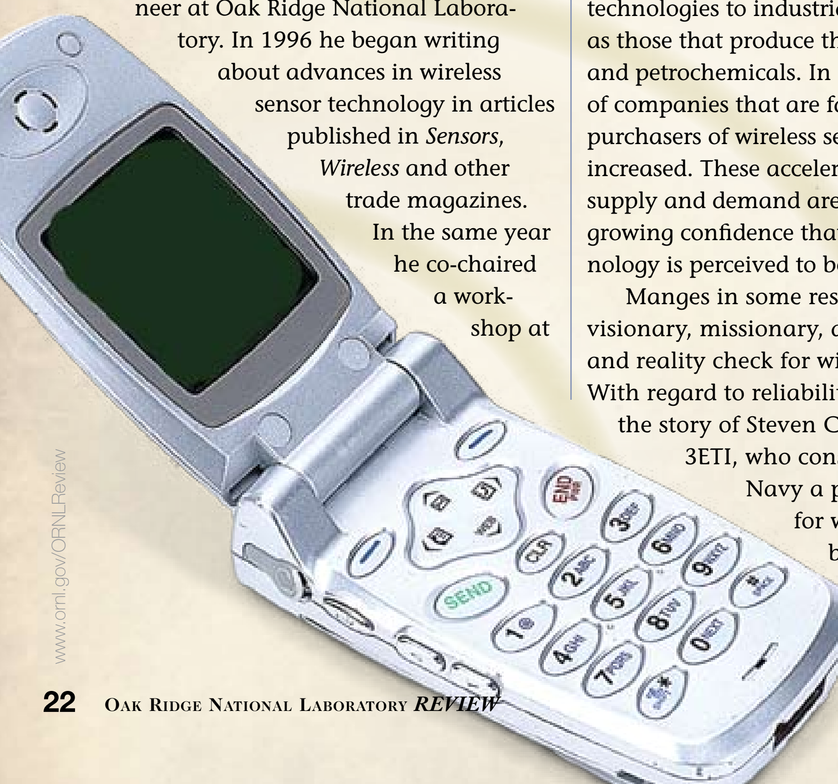
—C. K.

Myth: Wireless technologies are inherently unreliable

Reality: Modern wireless technologies are actually cheaper and more reliable

Owners of cell phones, television remote controls, smart car keys and devices with phone, e-mail and web access have in the past generally been willing to trade their wireless devices' moderate degree of unreliability in exchange for an enormous payback in convenience. In contrast, industrial firms and government departments have long shown resistance to replacing wired sensors and controls with wireless communication networks because of a widespread perception—some say a myth—that wireless technologies are fundamentally unreliable.

Few are more familiar with this myth than Wayne Manges, an electrical engineer at Oak Ridge National Laboratory. In 1996 he began writing about advances in wireless sensor technology in articles published in *Sensors*, *Wireless* and other trade magazines. In the same year he co-chaired a workshop at ORNL on the potential of industrial wireless technology.



In 1998 the National Academy of Sciences published a report based on the workshop talks. The report concludes that wireless sensors and controls present an opportunity to save energy, reduce emissions and enable more efficient use of raw materials. The compatibility of these potential benefits with the Department of Energy's industrial technology missions led DOE to develop a strategy designed to convince U.S. industries with large energy consumption to adopt wireless technology.

In 2007 three U.S. companies—Honeywell, Eaton and General Electric—along with three foreign companies began marketing wireless sensor-and-control technologies to industrial customers such as those that produce therapeutic drugs and petrochemicals. In 2008 the number of companies that are fabricators and purchasers of wireless sensors has sharply increased. These accelerating shifts in supply and demand are evidence of a growing confidence that wireless technology is perceived to be reliable.

Manges in some respects serves as a visionary, missionary, adviser, storyteller and reality check for wireless technology. With regard to reliability, he likes to tell the story of Steven Chen, president of 3ETI, who considered the U.S. Navy a promising market for wireless technology because cables on ships are heavy and costly. Chen called Manges and requested a demonstration on a Navy ship of ORNL's single-chip wireless sensor, a technology designed and fabricated using internal funding from ORNL's Laboratory Directed Research and Development program.

Manges and colleague Michael Moore drove to Jacksonville, Florida, and boarded the USS The Sullivans, a guided missile destroyer. The two researchers conducted a demonstration designed to show naval officers that a wireless chip can work reliably on a ship.

When several officers learned the purpose of the test, Manges heard them say, "This is a metal ship, and radio cannot work on a metal ship." The ORNL researchers smiled pleasantly and entered the engine room to conduct the first test.

"Our sensor chip was able to measure the temperature in the engine room and transmit the data reliably up to the third deck," Manges says. "A wireless signal sneaked up a catwalk connecting the decks to a computer on the top deck."

When Manges and Moore took the sensor chip to the ship's computer room, the commanding officer expressed doubt that the sensor could transmit a temperature signal because of the metal in the large computers and electromagnetic interference. "We were able to make and send sensor measurements of temperatures behind computer cabinets and elsewhere in the room because the signal bounces around the room and finds its way out," Manges explains.

"We tried one more test of the wireless sensor inside a metal room with a metal

door. Mike Moore left the room and took the sensor down the hall. We were able to read the hall temperature on a computer inside the metal room 20 feet away."

While it is true that radio signals cannot penetrate metal doors, it is also true that radio waves can sail through rubber gaskets used on ship doors to keep out water. "Our sensor radio uses spread spectrum signals that find their way out through door gaskets," Manges says, noting that spread spectrum technology was invented partly by Hedy Lamarr, the movie actress.

The commanding officer explains to Manges that using wireless sensors and controls to automate room temperature measurements and control the ship's temperature so it never exceeds 80°F would allow him to reassign the sailor charged with gathering and recording these measurements.

As a result of the successful ORNL demo, Navy officers looked for a supplier of wireless sensor and control networks. Their search led them to Steven Chen's company, 3ETI.

The lingering reliability myth of wireless technology includes the belief that a turned-on cell phone can shut down a wirelessly automated factory. Such an event is possible only if installers of a wireless network do not follow explicit standards. Manges chairs the committee that is developing the international standard for wireless automation.

Wireless technology is also plagued by the misconception that wireless sensors and controls cost more than conventional wired devices. Asia's construction boom has contributed to a quadrupling of the cost of copper wire. Likewise, the labor cost for installing wire has risen sharply. These costs, however, are only part of the story.

A Honeywell researcher recently told Manges about a customer whose company purchased a wireless tank level sensor for its ethanol refinery and experienced a return on investment in only 24 hours.

"This ethanol plant was having trouble with its wired tank level sensor because ethanol can corrode metallic electrical contacts," Manges says. "Honeywell installed a wireless tank level sensor and, by the end of the first day, when the wired one failed to halt the flow of ethanol into the tank, the wireless sensor sent a "stop" radio signal to the operator, preventing a costly ethanol spill."

Mounting evidence suggests that wireless technologies can help industry save energy and conserve materials. For years Manges has been extolling the potential of wireless sensor-and-control networks for helping industry and government agencies save energy and money while conserving materials and reducing health-threatening and climate-altering emissions to the environment.

"The simplest and cheapest way to save energy in most industrial plants with electric motors is to outfit each motor with a suite of inexpensive temperature, acoustic, magnetic and vibration sensors," says Manges. "These sensors will tell plant operators when a motor is overheating or vibrating too much or is otherwise near failure."

Most companies do not install wired instruments on their motors. For decades they have simply replaced their motors every two years under the assumption that they will soon wear out. This costly practice can lower productivity and waste useful materials in motors that might have lasted much longer.

"When electric motors waste energy, they give off heat," Manges says. "A wireless heat sensor can alert the operator that a particular motor is overloaded or has an electrical short."

Manges recommends that companies install cheap temperature sensors on their motors for condition-based maintenance. "Maintenance personnel should replace a piece of hardware based on its condition, not time of service," he says.

The U.S. nuclear power industry has become an "early adopter" of wireless technology, largely because wiring nuclear plants can cost as much as $2,000/ft. The Comanche Peak Nuclear Power Plant outside Dallas, Texas, currently boasts the world's largest network of industrial wireless sensors. The Nuclear Regulatory Commission looks to ORNL for guidance on the installation of wireless technologies in nuclear power plants.

In contrast with other myths that take a long time to develop and even longer to disprove, the myth that wireless technology is unreliable should be dispelled almost as quickly as it was formed. —*C. K.*

Jeff Smith

UT-Battelle was awarded the contract to manage Oak Ridge National Laboratory in late 1999. During the transition period up to April 1, 2000—UT-Battelle's first day of the contract—the incoming Leadership Team made its home in a set of rusted Quonset huts hastily erected during ORNL's postwar expansion. The group christened the old facility, with its peeling paint, drafty windows and creaky floors, the "Winter Palace," named after the home of the Russian czars. They were offered better environs, but the feeling was that the ramshackle buildings, still used as research and office space, symbolized the very real challenge that lay ahead on April Fool's Day. The point person responsible for modernizing ORNL was Jeff Smith, an Ohio native and former environmental researcher, who would be ORNL's new Deputy Director of Operations.

The focus of this issue is myths, including myths about ORNL. For instance, there is the often-heard comment that ORNL "glows in the dark." We all know that's not true, but sometimes these misconceptions aren't totally undeserved. What was your first impression of ORNL?

In October 1998 Dr. Bill Madia, who was then director of Pacific Northwest National Laboratory, said that Battelle was considering a bid on the Oak Ridge National Laboratory contract. He sent me down on a mission to scope it out. I had only been here once, about 10 years before, and didn't remember a lot about it. So I drove down Bethel Valley Road, and I passed up the entrance to the big parking lot. There wasn't anything that caught my eye that made me feel like I'd arrived. After driving a little ways I thought, "That must have been the entrance." So I turned around, came back and saw an old sign that read, "Visitor Portal." The sign was brown and falling apart--nondescript and certainly uninviting. That ugly sign was literally a visitor's first impression of ORNL. That image stuck with me.

On April 1, 2000, our first day as the new Lab contractor, we had a symbolic media event at the visitor center, which then was a depressing little office with orange upholstered chairs and chipped countertops. We said we were going to change this place.

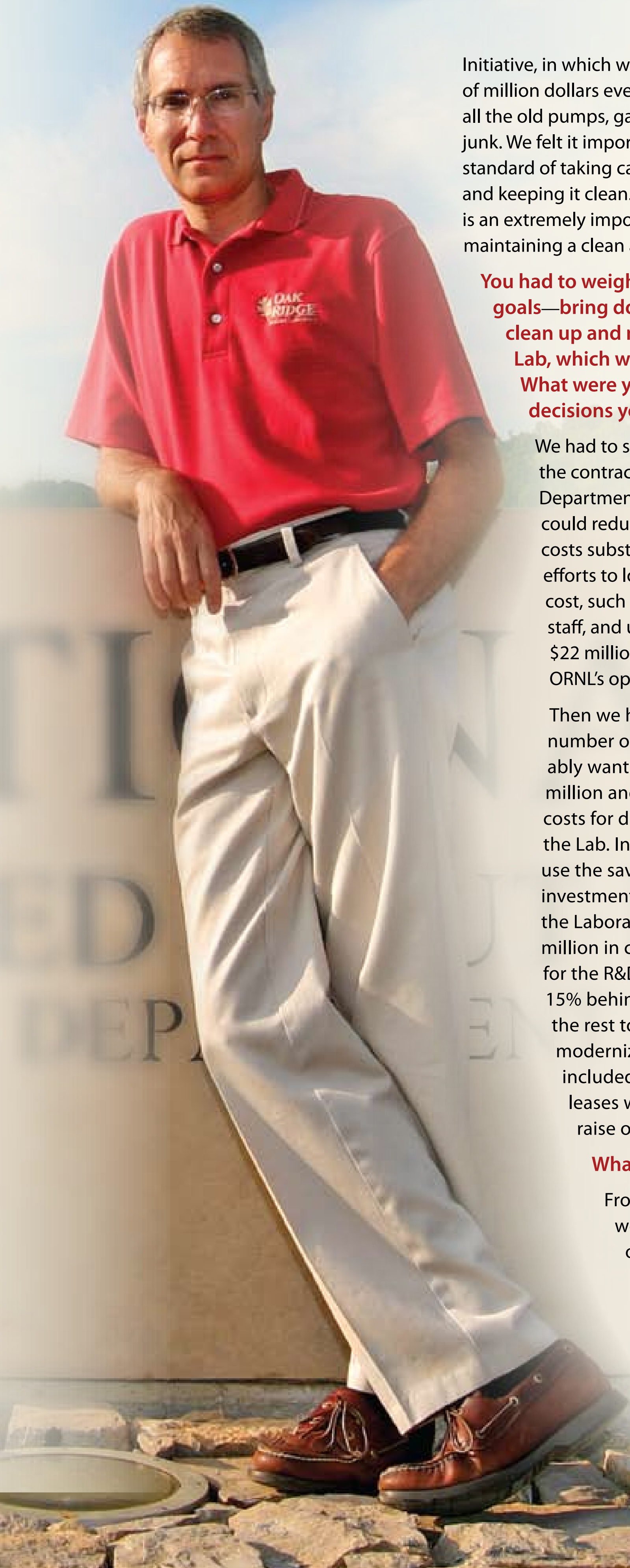
On that first day of our contract I had the guys get that old Visitor Portal sign for me. One day Nancy Gray, our former protocol officer, saw it hanging in my office and asked what it was for. I told her the story. She said, "I can't believe I never noticed it!"

Her reaction was symptomatic of the problem we faced. Nancy had worked at ORNL nearly her whole career, but like other staff had seen so many bad things for so long that she simply no longer noticed. But to a newcomer like me back in 1998, ORNL's campus made a huge impression, mostly negative. I started trying to draw attention to the importance of our image, and talk about how we could make a difference.

What was your biggest surprise, or biggest problem to solve, with cleaning up the Lab?

Director of Operations Herb Debban, Environmental, Health, Safety and Quality Director Kelly Beierschmitt and I had master keys to all of the locks. On Friday afternoons at four o'clock we would take walks into laboratories, basements and attics. We unlocked doors here or just walked around there, getting familiar with the place. We were absolutely amazed at how much junk had accumulated everywhere—old furniture, vacuum pumps, fans, valances—just "stuff." We would unlock closets and find them stacked full of old floor tiles. There were actually 300 doors stashed in the attic of the building that houses my office.

To clean up these legacy materials, we created the Legacy Materials Disposition



Initiative, in which we committed a couple of million dollars every year to cleaning up all the old pumps, gas cylinders and other junk. We felt it important to set a visible standard of taking care of the Laboratory and keeping it clean. And, of course, there is an extremely important safety element to maintaining a clean and orderly work space.

You had to weigh two contradicting goals—bring down the cost but clean up and modernize the Lab, which would cost money. What were your criteria for the decisions you made?

We had to strike a balance. During the contract proposal we told the Department of Energy that we could reduce ORNL's overhead costs substantially. We started efforts to lower the Laboratory's cost, such as reducing indirect staff, and ultimately eliminated $22 million from the cost of ORNL's operations.

Then we had a choice. A large number of staff understandably wanted us to take that $22 million and reduce overhead costs for doing business with the Lab. Instead, we chose to use the savings for long-term investments that would revitalize the Laboratory. We invested $9 million in closing the salary gap for the R&D staff, which were 15% behind the market. We used the rest to drive an ambitious modernization project that included private investment leases without the need to raise overhead rates.

What were the payoffs?

From a safety standpoint, we estimated that 25% of our accidents and injuries were a result of legacy problems that included working around old facilities and moving junk.

We have eliminated 1.2 million square feet of poorly contained space. Now our crafts workers aren't spending their resources trying to maintain all of that space and as a result can focus on things that are much more important to them and to the mission of the Laboratory.

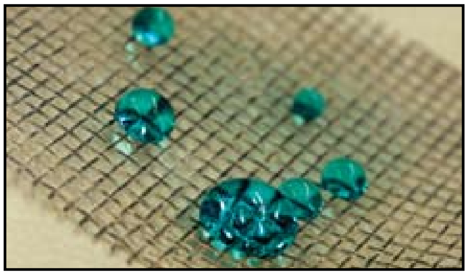
The look and feel of the Laboratory, and the impression it makes on your R&D staff, including prospective employees, can be even more important. A division director told me in those early days that he had quit trying to recruit more people. He genuinely believed it did more harm than good to bring people to his facilities, which in his case were located at the old Mouse House. Over the past five years we have gotten out of most of the run-down, expensive-to-maintain space and moved more than 2,000 staff into modern and energy-efficient facilities.

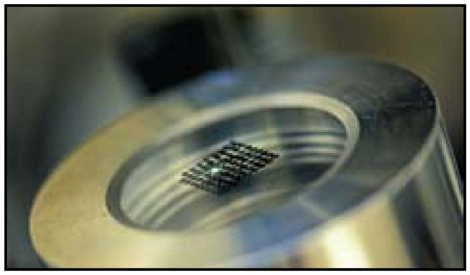
I know it doesn't sound very technical, but I don't want this Laboratory to be a turnoff. It didn't matter what kind of a technical problem we had. The place just didn't feel good. We owed it to our technical leaders to provide them a chance to express what they can accomplish.

You've discussed the importance of image. Is there any other change you've tried to make?

I guess the other thing I believe strongly is that solving complex problems requires collaboration among our scientists. Creative solutions sometimes require people to get together and mix it up. We have tried to create a new campus and a philosophy that facilitate this kind of interaction. For example, several years ago one of our staff had the vision that scientific computing was going to be a very big deal. Betting on this vision, we put an acre of computing space in a privately funded facility on our campus. That vision and our subsequent investments enabled the Department of Energy to put a leadership computing facility here that will house the world's most powerful open-science computer.

So I guess I would say that in addition to delivering good science, we have found it is also necessary to provide a vision, both literally and figuratively, of what a national laboratory should be.





NanoSH™ superhydrophobic technology, developed jointly by **John Simpson**, **Brian D'Urso** and **Steve McNeany**, all of ORNL's Measurement Science and Systems Engineering Division, Vinod Sikka (now retired) of ORNL's Materials Science and Technology Division, and Donald Speicher and Andrew Jones of Ross Technology Corp.

The NanoSH™ technology makes coatings completely water repellant by forming a microscopic air gap between the treated surface and water. (see *ORNL Review*, Vol. 41, No.2) The nanotechnology has a range of applications because water beads up and rolls off surfaces covered by thin glass or polymer sheets or powder-based coatings. By lowering friction between structural materials and water, NanoSH coatings will reduce the energy needed to propel waterborne vessels or to pump water through pipes. A NanoSH film can prevent corrosion on surfaces of metals and alloys. Unlike most hydrophobic films, the NanoSH coating is easy and inexpensive to make. NanoSH™ technology was funded by ORNL's Laboratory Directed Research and Development Program.

2-MGEM, optical anisotropy factor measurement system, developed jointly by Doug Mark, Baoliang "Bob" Wang, Andy Breninger, Tarik Hadid, Chad Mansfield, Bob Lakanen and Abebe Gezahegn, all of Hinds Instruments, and **Gerald Jellison**, **John Hunn** and **Christopher Rouleau**, all of ORNL's Materials Science and Technology Division.

The 2-MGEM microscope is used to characterize light polarization properties of a sample more accurately and reliably than can previous techniques. The technology measures pyrolytic carbon anisotropy to ensure quality control in the manufacture of coated fuel particles that will be used in the next generation of cleaner, more efficient nuclear power reactors. Nuclear power is considered by many to be one of the best near-term solutions to the world's increasing energy needs. Additional applications of 2-MGEM could include characterization of certain crystals, carbon compounds and thin-film coatings.

Funding sources for the project included the Department of Energy's Advanced Gas Reactor Fuel Development and Qualification Program.

Laser-induced fluorescence composite heat damage detector, developed jointly by **Chris Janke** and **Cliff Eberle** of ORNL's Materials Science and Technology Division, **Curt Maxey** and **John Storey** of the Energy & Transportation Science Division, **Art Clemons** of the National Security Directorate, and Walt Fisher, Eric Wachter and Josh Fisher of Galt Technologies.

Researchers have helped develop a portable, lightweight heat damage detector that provides rapid and accurate assessments of early heat damage in fiber-reinforced polymer matrix composites in both military and commercial aircraft. Composites have a high strength-to-weight ratio, increasing aircraft fuel efficiency without compromising safety.

These advanced materials, however, are vulnerable to heat damage, which can significantly degrade their desirable mechanical properties. The detector, which induces and analyzes composite fluorescence, is the first of its kind that can detect hidden heat damage without causing destruction of the aircraft part under inspection. The cost of locating and repairing early heat damage in an aircraft composite part is estimated to be 10 times lower than replacing the part. The Office of Naval Research sponsored the development of the detector.

Still the Leader

ORNL has won 140 R&D 100 awards in the past 45 years.

Oak Ridge National Laboratory researchers received six R&D 100 Awards in 2008, boosting ORNL's awards total to 140 since the competition began 45 years ago. ORNL has won more R&D 100 awards than any other Department of Energy laboratory.

Often called the Oscars of invention, the awards were announced June 30 by *R&D Magazine*, which issues the awards in recognition of the year's most significant technological innovations. ORNL was honored for innovative technologies in areas ranging from advanced materials to national security.

"This is an impressive example of the diversity and depth of the Laboratory's research talent," said ORNL Director Thom Mason. "These awards demonstrate our ability to translate breakthroughs in fundamental science into applications that address important technological challenges."

Vinod Sikka, who recently retired from ORNL's Materials Science and Technology Division, is listed on two of this year's awards. *R&D Magazine's* office believes that Sikka, with 12 awards, is the all-time leader in R&D 100 Awards.

The above ORNL inventions and inventors were recognized at the R&D 100 awards ceremony held in October in Chicago.

Adaptive band excitation controller and software for scanning probe microscopy, invented jointly by **Stephen Jesse** and **Sergei Kalinin** of DOE's Center for Nanophase Materials Sciences at ORNL and Roger Proksch of Asylum Research Corp.

The adaptive band excitation controller and software represent a new family of scanning probe microscopy techniques that allows faster measurements of energy dissipation than have been obtained previously. SPM images a surface by mechanically moving a needle-like probe in a line-by-line raster scan of a specimen and recording the probe-surface interaction as a function of position.

These techniques enable researchers to carry out functional imaging and manipulation down to the nanometer and atomic scale. Jesse and Kalinin replaced the single sinusoidal excitation signal common to existing SPM systems with a complex digitally synthesized signal spanning a band of frequencies. Using polytonal excitation enables characterization of tip-surface interactions and energy dissipation mechanisms in unheard of detail. The novel SPM technique also can be used to characterize a sample's electrical, magnetic and mechanical energy conversion properties at the nanoscale.

The research was sponsored by ORNL seed money and DOE's Office of Basic Energy Sciences and Division of Materials Sciences and Engineering.

Cratos V nano-wool™, developed jointly by Roland Seals of Babcock & Wilcox Technical Services Y-12 and **Paul Menchhofer**, **Vinod Sikka** and **Fred Montgomery** of ORNL's Materials Science and Technology Division.

Compared with aluminum, multi-wall carbon nanotubes possess half the density, 480 times the tensile strength, 10 times higher thermal conductivity and 27 times higher electrical conductivity. Despite their great properties, the exorbitant cost of producing multi-wall nanotubes has discouraged their use. As a result of a four-year research project related to cutting tool materials, the participants developed a novel catalyst and a simple process for low-cost production of high-purity, carbon nanotubes that exhibit improved thermal stability.

A product of the process, dubbed Cratos after the Greek god of strength and power, is Cratos V nano-wool, which is composed of multi-wall carbon nanotubes. Tests show that Cratos V carbon nanotubes can be used to reinforce grinding wheels, cutting tools and metal composites as well as produce electrically conducting polymers and flexible heating elements. For example, diamond grinding wheels reinforced with nano-wool can be made using less diamond, reducing wheel cost. Carbon-nanotube-reinforced polymer composites will also be widely utilized within the automotive, aeronautic and defense arenas for such diverse applications as automobile body panels and lightweight, bullet-resistant body armor.

Funding for the project came from the Y-12 National Security Complex's Plant Directed Research and Development program.

SpaciMS: spatially resolved capillary inlet mass spectrometer, developed jointly by **William Partridge Jr.**, **Jae-Soon Choi**, **John Storey** and **Sam Lewis** of ORNL's Energy & Transportation Science Division; Neal Currier and Aleksey Yezerets of Cummins, Inc.; Alexandre Goguet and Christopher Hardacre of CenTACat, Queen's University in Belfast, Northern Ireland; David Lundie, Terry Whitmore and Adrian Jessop, all of Hiden Analytical in Warrington, United Kingdom, which has commercialized the SpaciMS; and Gerald DeVault and Robert Smithwick III, both of the Oak Ridge Y-12 National Security Complex.

The SpaciMS, invented jointly by ORNL and Cummins, measures fast changes in gaseous chemical composition inside confined-space chemical reactors, such as automotive catalysts. The instrument uses gas sampling capillaries positioned inside the chemical reactor to pinpoint, measure and map concentrations of diverse gaseous pollutants, such as nitrogen oxide, carbon monoxide and carbon dioxide. Measurements of chemistry evolution inside the chemical reactor under realistic operating conditions provides much greater understanding of catalyst chemistry than has been possible previously by measuring inlet and effluent composition alone. The SpaciMS has provided unprecedented insight into transient chemistry inside the small channels of automotive catalysts, fuel reformers and fuel cells. The invention also has been used to study aspects of diesel engine performance. The technology was used in the development of the groundbreaking 2007 Dodge Ram heavy-duty pickup truck engine-catalyst system, which met 2010 emissions control standards three years ahead of schedule.

Funding for the development of SpaciMS was provided by ORNL's Laboratory Directed Research and Development program and DOE's Office of Heavy Vehicle Technology and Office of FreedomCAR and Vehicle Technologies.

...and the WINNERS are...

Accomplishments of Distinction at Oak Ridge National Laboratory

Keith Joy

Keith Joy, Oak Ridge National Laboratory's Small Business Program Manager, has been named the ***Department of Energy's Management and Operations Program Manager of the Year***. The director of DOE's Office of Small and Disadvantaged Business Utilization writes in a letter to Joy: "Your strong work ethic and commitment to increasing small business participation in DOE contracting activities enable the Department to complete its ever important mission of safeguarding our nation's resources." The letter notes that small businesses are leaders of innovation, create two-thirds of the nation's net jobs and serve as the engine that drives the U.S. economy.

ORNL researchers **Richard Bass, Stuart Daw** and **Amit Goyal** have been named ***UT-Battelle Corporate Fellows***. The honor recognizes their long-standing leadership in their respective fields of science and engineering and their contributions to ORNL's reputation for excellence. **Bass** was recognized for outstanding contributions to ORNL in advanced computational structural mechanics and nuclear safety technologies. He is a world leader in the development and application of advanced computational methods and computer codes for structural analyses of complex components including nuclear reactor pressure vessels. He currently manages the U.S. Nuclear Regulatory Commission program at ORNL that develops probabilistic structural safety assessment technology for nuclear power plants. **Daw** has pioneered the application of chaos theory and nonlinear dynamics to energy technologies, including gas-fluidized beds, internal combustion engines and pulsed combustion. His ground-breaking efforts in developing practical uses for chaos theory in engineering applications have been widely recognized in industry. **Goyal** has done pioneering research that has had a profound impact on the field of high-temperature superconductivity, both in fundamental materials science and in the transition of scientific discoveries from the laboratory to the marketplace. His innovations have provided elegant solutions to achieving essentially single-crystal-like behavior in long lengths of superconducting material, using techniques that are industrially scalable and cost effective, as well as creating self-assembled, nanoscale defects within superconductors that dramatically enhance their properties.

Thomas Thundat has been elected ***fellow*** of the ***Electrochemical Society***.

Jim Bogard has been named ***fellow*** of the ***Health Physics Society***.

Slava Danilov has received one of two accelerator-related prizes awarded by the European Physical Society Accelerator Group every two years. Danilov's EPS-AG ***Accelerator Prize*** cited him "for numerous contributions to accelerator physics," including a successful laser-stripping experiment.

ORNL's **Green Transportation Initiative** has received a ***White House Closing the Circle Award***, which recognizes outstanding federal environmental stewardship practices. The award, presented by the Office of the Federal Environmental Executive, cited ORNL's efforts in reducing energy consumption and using alternative fuels in its work fleet. About 25% of the work fleet consists of flex-fuel vehicles that run on E-85, which is 85% ethanol and15% gasoline.

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