LOS ALAMOS

ENERGY SECURITY

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Los Alamos NATIONAL LABORATORY EST. 1943

Not Your Mother's National Security

Old threats produced science needed for the new

If you visit Los Alamos National Laboratory's website, you'll find this statement: "The mission of Los Alamos National Laboratory is national security." That sounds simple enough until you try to define national security. To many of us, and certainly to our parents, the term "national security" often conjures images of agressive acts that threaten our liberty—our ability to self-govern according to U.S. principles. It was just such threats that led to the creation of Los Alamos National Laboratory during World War II and guided its mission throughout the Cold War. But is that all there is to national security?

George Kennan, diplomat and chief architect of U.S. Cold War foreign policy, expanded the definition of national security to "the continued ability of this country to pursue its internal life without serious interference." While many problems—such as disease, natural disasters, and widespread poverty—could fit into this broad definition, few things could interfere more with the American way of life than a lack of affordable energy.

What makes energy so special? Abundant, affordable energy is the enabler that underpins solutions to nearly every other problem. Try responding to pandemics, forest fires, or earthquakes without sufficient energy on demand. Try eliminating poverty without abundant and affordable energy (see figure on page 3). For national security traditionalists, try mobilizing the nation's armed forces and the industries that support them without sufficient energy resources. Even if you only accept outright foreign conflict as a national security threat, you still must put energy security

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Bombs Into Ploughshares

Things have changed quite a bit since the biblical Isaiah prophesied that nations would "beat their swords into ploughshares." The cutting-edge science that has supported this nation's ultimate "sword" can be turned into far more impressive things than ploughshares. The nation's huge investment

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Los Alamos Energy Security, produced by Los Alamos National Laboratory, is a quarterly publication that presents energy issues of critical national and global importance and highlights the Laboratory's research and development aimed at addressing those issues. For more information about Los Alamos National Laboratory's energy security research and development, go to **www.lanl.gov/energy**.

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Los Alamos
NATIONAL LABORATORY

Energy is Essential to National Security

Terry C. Wallace, Jr.
Associate Director for Strategic Research
Los Alamos National Laboratory

The mission of Los Alamos National Laboratory is national security with three distinct components: certifying a reliable nuclear deterrent, providing technical solutions to help protect the nation from weapons of mass destruction and terrorism, and providing scientific solutions to emerging threats. This last category, *emerging threats to the nation*, includes a very broad range of phenomena which will challenge the fundamental security of the United States through economic attack, degraded quality of life, and limited access to key resources. Clean, plentiful, and affordable energy is an essential ingredient to our security.

The U.S. accounts for about one quarter of the energy consumed globally. Many other countries, recognizing the relationship between economic vitality and national stability, are aggressively moving to increase their energy production. Growth in energy consumption is particularly profound in Asia where both China and India will surpass the U.S. in the coming decades. The implications are obvious; competition for energy access will intensify and choices about energy production will have tremendous impacts on the environment. Presently two thirds of global energy production come from fossil fuels which produce about 12,500 cubic km/year of CO_2 and other greenhouse gases. The cascading environmental effects of anthropogenic greenhouse gas production are often debated, but it is clear that climatic impacts and ocean acidification are profound. By most estimates, about one half of the oil and natural gas that is recoverable with present technology has already been mined, and the global demand for liquid fuels is increasing by 3 percent per year.

As the nation's premier resource for solving multidisciplinary scientific challenges, Los Alamos National Laboratory has a tremendous role to play in energy security. The scope of energy security is extraordinary, and many different groups (universities and other national laboratories) are working on facets of the problem. However, Los Alamos has some unique capabilities that must be brought to bear on the energy challenge. For its entire national security mission, the Laboratory must lead in scientific discovery and producing integrated solutions to complex systems. Skills and capabilities developed for nuclear stockpile stewardship are directly applicable to energy security. These include Los Alamos's preeminent position in materials science, computational resources (machines, codes, and people), complex natural systems, and innovation in measuring and monitoring phenomena. Anticipating emerging threats to the nation and solving profound problems with science and technology is the future (and the past) of Los Alamos National Laboratory.

Not Your Mother's National Security

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at the top of your concerns. New Mexico Governor Bill Richardson, while serving as the U.S. Secretary of Energy, put it bluntly:

> Oil has literally made foreign and security policy for decades. Just since the turn of [the 20th] century, it has provoked the division of the Middle East after World War I; aroused Germany and Japan to extend their tentacles beyond their borders, the Arab Oil Embargo, Iran versus Iraq; the Gulf War. This is all clear.

There can be no national security without energy security, so what does the energy security landscape look like today?

The century-old competition for oil is still part of the picture but with some new twists. Debate exists over whether oil is running out or if enough is left to meet demand for several more decades, but there are two points upon which most agree: (1) whatever oil reserves are left will be harder and more expensive to access, and (2) competition for remaining reserves will intensify greatly as population rises and China and India strive to improve their economies. The U.S. will not bounce back easily, as it did in the 1970's, from another oil crisis. Short supplies and higher prices will not be artificially imposed next time.

More than 50% of oil consumed in the U.S. is imported from foreign regions (many of which are politically unstable), and projections show those imports up to 70% by the year 2020. Such dependence on other countries for our primary transportation fuel has already had, and will continue to have, serious implications for U.S. national security.

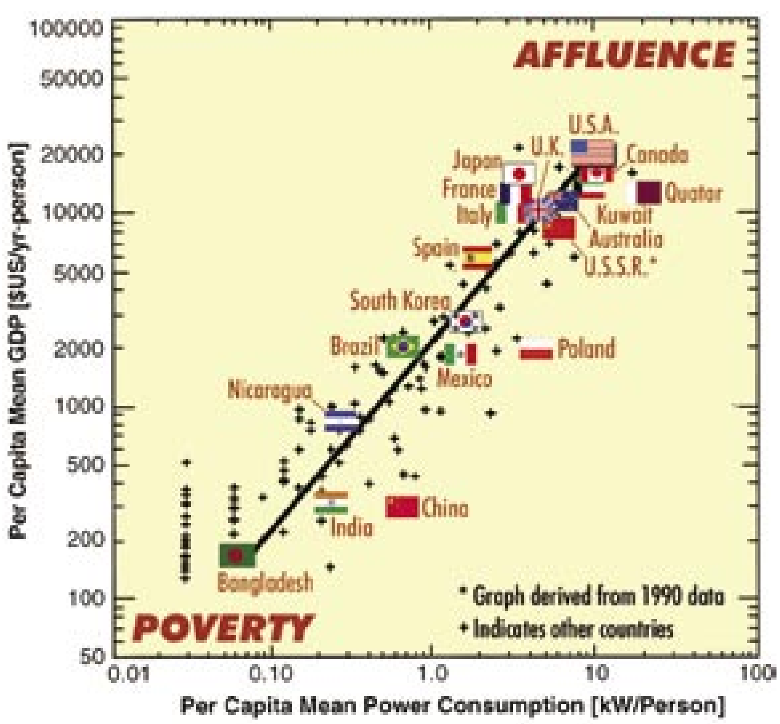
But energy security is now far more than just competition for oil. Electricity production also faces a serious obstacle. Unlike oil, coal reserves in the U.S. are abundant and readily available, but burning them as we do now would most likely exacerbate global climate change. While debate rages over the causes of climate change, compelling scientific evidence indicates that all nations would be wise to decrease carbon emissions from fossil fuel use sooner rather than later. China and India will advance their economies the same way we did, by burning their vast coal reserves. How will we fuel our economy and theirs without triggering a potential environmental catastrophe? Even with an abundant domestic energy resource we find ourselves entangled in an international problem.

Moving energy around will also be more problematic as new generating capacity overburdens the aging power grid. An old and inefficient power grid is not only more vulnerable to malicious threats, it also wastes significant amounts of current, which translates into more fuel consumption and more emissions.

Finally, there is another less obvious link between energy and the future security of the U.S. The nations of the world are ripe for revolutionary changes in the way they produce and use energy. British economist Carlotta Perez has shown that a nation's economy will rise or fall depending on whether it leads or lags behind during a technological revolution. During the recent information revolution, the U.S. led the world and achieved economic dominance. Will the next big technological revolution focus on energy? And if so, will the U.S. have the foresight to get in front on energy innovations and maintain its economic dominance?

So the mission of Los Alamos is national security, but that mission includes energy security, which means performing the basic and applied science to solve problems emerging on the energy landscape. This publication, the very first issue of *Los Alamos Energy Security*, exists to promote the important idea that there can be no national security without energy security, and that even though national security today is not your mother's national security, the threats of past decades have spawned the very scientific and technological capabilities that can solve threats to our energy and national security today.

— Anthony Mancino



Per capita GDP related to per capita energy consumption. A nation's wealth is directly related to its access to affordable energy. What will happen to resource availability and the environment as countries like India and China move up the sloped line?

Source: Watts, Robert G. Engineering Response to Global Climate Change: Planning a Research and Development Agenda. *CRC Press LLC: Boca Raton, 1997.*

Rockets, Golf Carts, and the Future of U.S. Transportation

A brief history of hydrogen and fuel cell R&D at Los Alamos National Laboratory

Above: World-renowned Hungarian aeronautical engineer Dr. Theodore von Karman was instrumental in persuading the U.S. government to develop nuclear propulsion for rocket systems. With the rise of Adolf Hitler, von Karman left his university position in Germany to become the director of the Guggenheim Aeronautical Laboratory at the California Institute of Technology.

Background photo: In 1967, the Phoebus-2A is transported on rails to its test station at Jackass Flats, Nevada. It was the most powerful nuclear rocket reactor ever built, able to operate at 4100MW with a hydrogen flow of 120kg/s for nearly 80 minutes.

For more than 50 years, Los Alamos scientists and engineers have worked to understand hydrogen isotopes—their production, purification, storage, interactions with other materials, and their release as applied to thermonuclear weapons. The Laboratory's hydrogen expertise got a massive boost in 1955 when the United States, at the urging of renowned aeronautical engineer Theodore von Karman, initiated Project Rover to develop a nuclear rocket engine for use in defense systems and space exploration. These engines used hydrogen stored as a cryogenic liquid then heated in the reactor core to temperatures as high as 2500K as the propellant. In the 17 years of the Rover Project, the Los Alamos Scientific Laboratory built and tested 13 research nuclear rockets and worked with and transferred technology to the Astronuclear Laboratory of the Westinghouse Electric Corporation on an additional 8 engine tests under the associated Nuclear Engine for Rocket Vehicle Application (NERVA) program. During the Rover/NERVA program, Los Alamos used more hydrogen than NASA.

When the first oil embargo occurred in 1973, Project Rover scientists and engineers thought hydrogen would make an excellent transportation fuel, and over the next few years converted both a pickup truck and a Buick passenger car to run on hydrogen by modifying the vehicles' internal combustion engines and storing liquid hydrogen on-board in cryogenic dewars. In 1977, Laboratory researchers converted a golf cart to utilize a hydrogen-oxygen phosphoric acid fuel cell for electrical power. That same year, the newly established Department of Energy (DOE) awarded the first Fuel Cells for Transportation program to Los Alamos. This research project has continued without interruption until today making it one of the longest running non-defense programs at the Laboratory. It has grown into the DOE's premier R&D effort in low-temperature fuel cells and supporting technologies.

Work at Los Alamos over the last 28 years has enabled the emerging fuel cell industry, and the Laboratory holds several seminal patents required by product developers. Arguably, the breakthrough that brought the polymer electrolyte membrane (PEM) fuel cell

In 1979, tanks of hydrogen and oxygen feed the fuel cells powering Los Alamos's golf cart. During the 70's, Los Alamos scientists and engineers also converted a Dodge pickup truck and a Buick Century sedan to operate on fuel cell power.

out of the space program and enabled its consideration as a ubiquitous power conversion technology was the development in the late 1980's and early 1990's of the thin-film low-platinum electrode by Ian Raistrick and Mahlon S. Wilson. Their work dramatically lowered the required precious-metal platinum catalyst loadings by a factor of more than 20 while simultaneously improving performance. This electrode approach is now used by fuel cell manufacturers and researchers worldwide.

Another Los Alamos innovation dramatically improved cell tolerance to hydrogen impurities enabling low-temperature PEM fuel cells to operate not only with pure hydrogen, but also with hydrogen-rich gas streams derived from hydrocarbon fuels (such as gasoline, methanol, propane or natural gas). Other significant Los Alamos technology advances include development of processes to generate hydrogen-rich gas streams on demand from hydrocarbon fuels, development of fuel cell test procedures and performance characterization methodologies, and fundamental data-supported modeling of fuel cell performance.

From the beginning of its fuel cell program, Los Alamos researchers have worked closely with industry. One key example was the establishment of the Los Alamos/General Motors (GM) Joint Development Center (JDC) at the Laboratory in 1991 funded by GM and the DOE. The JDC effort focused on development of the Electrochemical Engine (ECE)—a complete PEM fuel cell power system fueled by methanol converted on demand to a hydrogen-rich gas. At that time, liquid fuel was considered crucial to the acceptance of fuel-cell powered vehicles because it allowed use of the mature transportation-fuel distribution infrastructure. A parallel core research activity, in what is now the Electronic and Electrochemical Materials and Devices Group, was making enabling breakthroughs that were soon incorporated into the Electrochemical Engine. The project developed and demonstrated complete 10kW and 30kW electrochemical engines. As the ECE project neared its end, GM took the knowledge and expertise gained at the JDC and established their corporate fuel cell R&D center in upstate New York.

Following the Electrochemical Engine project, the engineering research effort shifted toward making "stack quality gas" from gasoline. In 1997, a team from Engineering Sciences and Applications' Energy and Process Engineering Group participated in an experiment in Cambridge, Massachusetts that coupled a Los Alamos fuel-product cleanup system with a gasoline reformer developed by Arthur D. Little and a PEM fuel cell stack developed by Plug Power. To great acclaim, the integrated system generated the world's first electrical power from a low-temperature fuel cell operating on gasoline reformate. The Laboratory/industry team received the Partnership for a New Generation of Vehicles Medal in a 1998 ceremony at the White House for "Government-Industry Teamwork."

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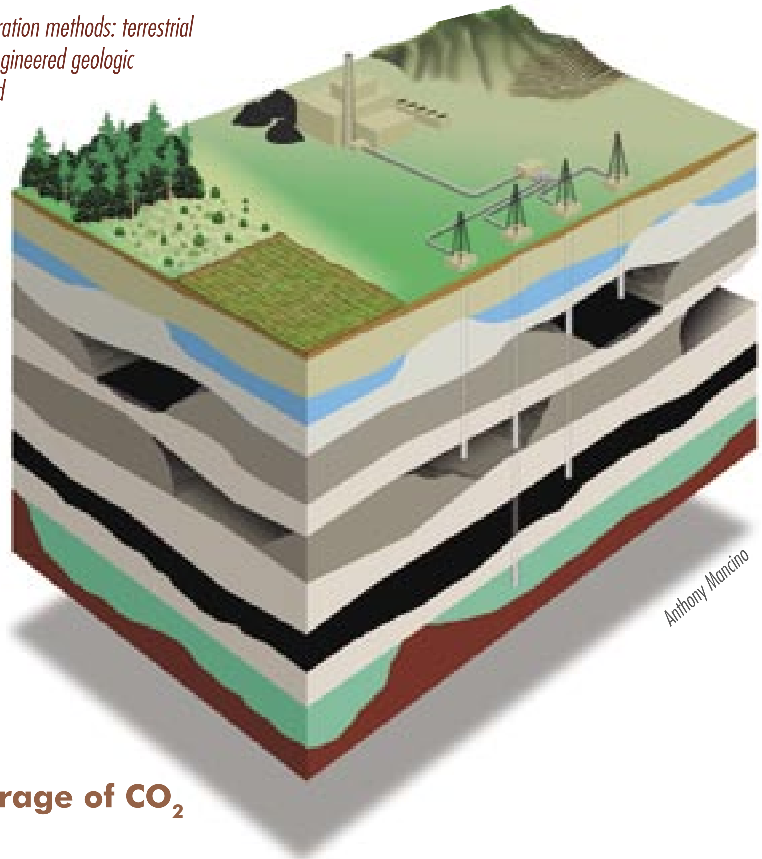
"General Motors and Los Alamos have a long and successful history working together to research and develop fuel cells for automobiles. This collaboration, supported by the Department of Energy, serves as the technical foundation for the intensive development effort in fuel cells at General Motors today."
— *GM Director of Fuel Cell Activities*

The Sequel—General Motors' latest fuel cell concept vehicle (photo courtesy of General Motors).

Los Alamos is working on three land-based sequestration methods: terrestrial (enhanced carbon uptake by biological sytems), engineered geologic (storing carbon in deep saline aquifers and depleted oil and gas wells), and mineralization (a concept pioneered at Los Alamos in which CO_2 is reacted with magnesium-rich silicates to form a stable solid).



Engineering the Subsurface

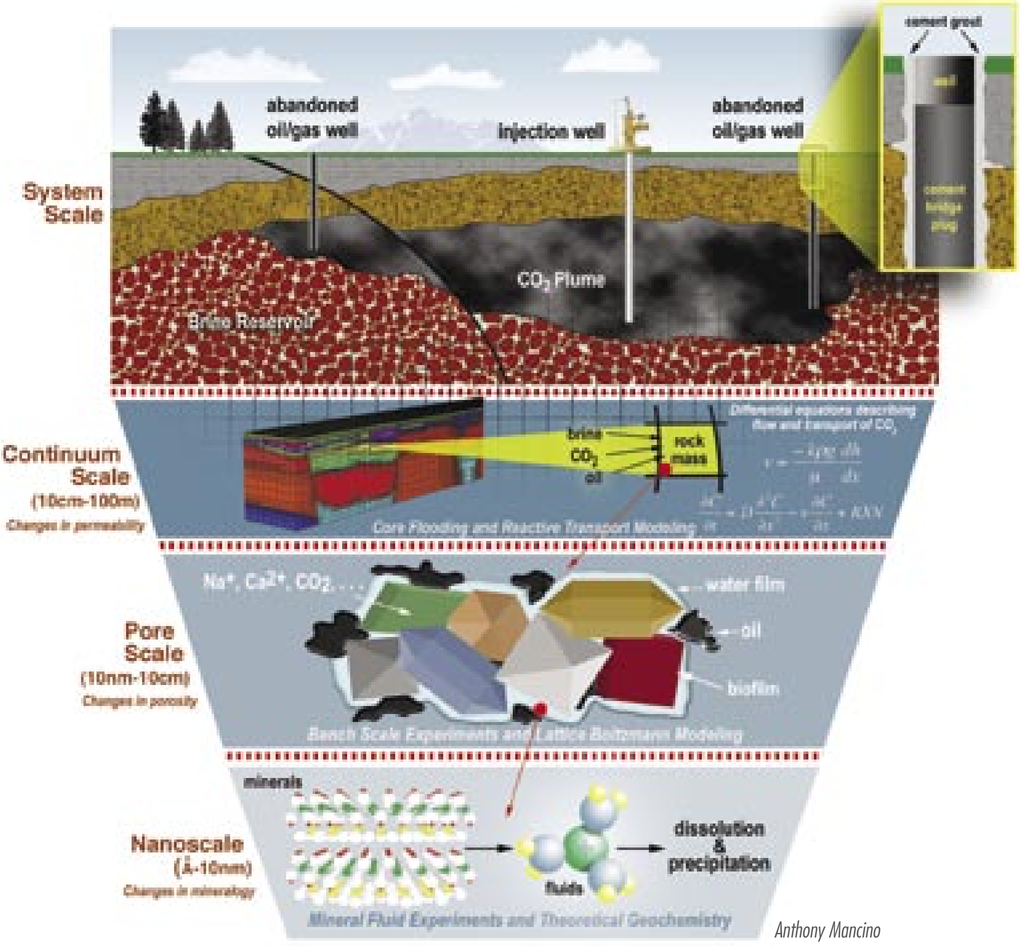
From underground testing to geologic storage of CO_2

While alternative and renewable energy sources will gradually increase their contribution to the world's energy supply, most energy projections agree that conventional fossil energy generation will continue to dominate for at least the next 15 years. U.S. energy demand alone currently results in billions of tons of carbon dioxide emissions annually. Those emissions, and the rest of the world's, could have negative effects on global climate. Is there anything we can do with carbon dioxode emissions over the next couple of decades? While no single approach will solve the problem completely, one answer may be to store the CO_2 where it can't affect the atmosphere. We may be able to put a lot of the carbon back where we got it from in the first place—deep underground.

Subsidence craters resulting from underground nuclear testing at the Nevada Test Site.

Carbon sequestration, the capture and long-term storage of CO_2, is one of the current energy security grand challenges. Los Alamos is working on many carbon sequestration methods, including terrestrial (enhancing the natural uptake of carbon by biological systems), mineralization (accelerating the conversion of CO_2 into a stable mineral), and ocean (using clathrate-hydrates to trap CO_2 at the bottom of the sea). The Laboratory also has a strong effort in the separation and capture of CO_2, the critical first step upon which all sequestration methods depend. But this story focuses on one method only—the storage of CO_2 in engineered geological reservoirs. It's a story that goes back to the early days of Los Alamos National Laboratory when understanding and engineering the subsurface became crucial to national security.

The earth sciences at Los Alamos have their roots in engineering the subsurface for underground nuclear testing. The ability to predict the performance of engineered geological systems and ensure containment of the tests was absolutely critical. Natural systems consist of a wide range of materials and composites whose properties must be predicted on vast length and time scales. The complexity of natural systems imparts uncertainty both in the characteristics of the system itself and in the behavior of the system under extreme conditions. In order for predictions to be meaningful, these uncertainties must be captured accurately. To address this challenge,



Anthony Mancino

The scientific challenge of carbon sequestration requires work at many levels, from basic nanoscience to prediction and engineering at the large system level. At the molecular scale, Los Alamos researchers use experiments, observation, and theory to determine the geochemical phenomena that occur when geomaterials and engineered materials like cement interact with CO_2 and brine. These processes have a direct effect on the porosity and permeability of rocks, thereby impacting fluid flow. By coupling molecular phenomena to flow, one can jump up in scale. Los Alamos is using its sophisticated reactive-transport computational codes to make this jump, refining and validating the predictions with large-scale experiments, including field-scale collaborations with industry, universities, and other national labs. Making the final move up in scale to the system level, Los Alamos is developing a framework that links the process level phenomena to the system scale via probabilistic approaches that can accommodate uncertainties.

the Department of Energy invested resources at Los Alamos to build broad expertise in geomaterials and engineered geologic systems. Combining experiment, observation, and theory, tools have been developed to predict system behavior over necessary length and time scales. These tools can characterize geologic systems (using novel geophysics), explore the behavior of geomaterials under extreme conditions, predict reactive flow in porous media, and track atmospheric transport and dynamics.

One of the first times this weapons-related expertise crossed over into the energy realm was at the world's first hot dry rock facility. At Fenton Hill, just west of Los Alamos, Laboratory researchers drilled to depths of over 14,000 feet, fractured the hot dry rock formation, and circulated water through it to mine the earth's geothermal energy. The pioneering work carried out at Fenton Hill showed that hot dry rock could be a practical source of energy. Germany and Japan had contributed funds and personnel to the project and used the knowledge gained at Fenton Hill to start similar projects in their countries. Expertise gained at Fenton Hill also fed back into Los Alamos's core capabilities and was applied to, among other things, oil and gas exploration and nuclear waste repository science, again showing the symbiotic relationship between the Laboratory's defense and energy research and development.

Today that relationship is at work again as Los Alamos applies the very same capabilities to the problem of geologic carbon sequestration. In geologic sequestration, CO_2 is first captured (initially from large point sources such as fossil-fueled power plants) and compressed to form a fluid. This supercritical CO_2 is then injected into the deep subsurface thousands of feet underground. The reservoir rock's permeability must be sufficiently high to accept the CO_2. The CO_2 is buoyant relative to the groundwater, so to prevent the movement of CO_2 back to the surface, the cap rock at the top of the reservoir must have low permeability. To be effective, the CO_2 must remain contained for hundreds or perhaps thousands of years to have a

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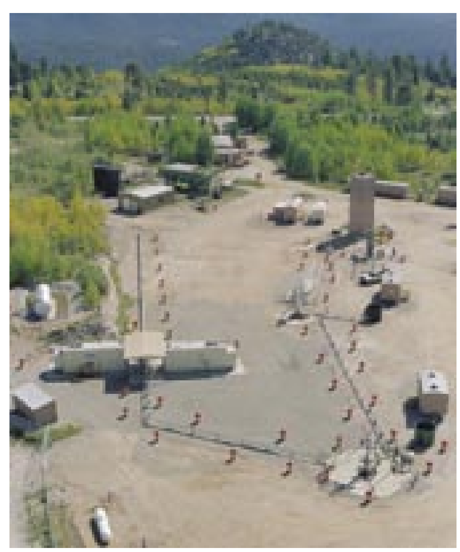
At Fenton Hill, about 40 miles west of Los Alamos, researchers demonstrated the feasibility of mining useful geothermal energy from hot dry rock.



Los Alamos Superconductivity Researcher Named Asian American Engineer of the Year

A University of California scientist working at Los Alamos National Laboratory, widely known for his innovations in the fields of electronic materials and high-temperature superconductivity, has been named the 2005 Asian American Engineer of the Year by the Chinese Institute of Engineers USA (CIE/USA).

Quanxi Jia, a Laboratory Fellow since September 2003 and currently the Device Team Leader in the Superconductivity Technology Center of the Materials Science and Technology Division, is the author/co-author of more than 240 refereed journal articles and nine book chapters. Jia has 22 patents for electronic materials and devices and 10 more pending. He is the winner of two R&D 100 awards for his underground radio work and for flexible superconducting tape.

Jia's fields of expertise are in the growth of metal-oxide films, the fabrication of electronic devices, and the structural/electrical characterization of electronic materials.

Quanxi Jia, Asian American Engineer of the Year

Catherine Padró, Materials Science and Technology Engineer

The CIE/USA award recognizes engineers who have made outstanding contributions to the engineering profession, the public welfare and/or humankind. This is the fourth consecutive year that a Los Alamos scientist has received the award.

Los Alamos Engineer Helps Beijing Olympics Go Green

Catherine Padró, an engineer with the Laboratory's Materials Science and Technology Division, served as Head of Delegation for the U.S. team during a recent trip to China for continued discussions on a joint project to demonstrate renewable hydrogen production during the 2008 Beijing Summer Olympics. Working with engineers from Tsinghua University, the project will include a building-integrated photovoltaic array, an electrolyzer, and compression/storage. The demonstration will be integrated with a BP-sponsored hydrogen dispensing station in the Hydrogen Park in northwest Beijing which will refuel buses and passenger vehicles used to transport visitors and athletes.

Los Alamos Delegation Invited to Canadian Oil Sand Plants

On March 14-18, the Canadian Consulate General invited a Los Alamos delegation to visit the Province of Alberta for a briefing on current oil sand and carbon sequestration research in Alberta. The Los Alamos group met with researchers from the Universities of Calgary and Edmonton, the Alberta Research Council, and production engineers from Suncor and Syncrude—both oil sand producers. A visit to oil sand production facilities near Ft. McMurray was the high point of the trip.

North American energy security is important for both Canada and the U.S., and Alberta's hydrocarbon resources are strategically important to the U.S. The recent visit helped Los Alamos and Canadian researchers to identify areas for future collaboration. A reciprocal visit by a Canadian delegation is in the planning stage.

Syncrude oil sand plant in Alberta, Canada

Ploughshares continued from page 1

in Los Alamos National Laboratory has fostered a host of unique scientific and technical capabilities that can be applied to many challenges apart from military defense. For energy security, these capabilities are being used to

- convert the U.S. transportation economy into a clean, domestically-fueled hydrogen-based system,
- enable coal use without harmful greenhouse gas emissions,
- replace electricity transmission lines with superconducting cables that have virtually zero current loss,
- prevent global climate change by accelerating natural carbon intake processes (biological and mineral),
- store industrial CO_2 emissions in safe geological wells,
- reduce the hazards of nuclear energy by making the materials safer and proliferation-resistant,
- predict the effects of global climate change,
- foresee vulnerabilities in our electric and transportation systems before they fail or are exploited maliciously,
- make unused water reserves available for electricity generation and other industrial uses,
- increase the efficiency of solar cells,
- pursue the holy grail of energy research, nuclear fusion.

While the nation benefits directly from the Laboratory's work on these energy-related problems, another less obvious national benefit results from such work.

We're a patriotic bunch here at Los Alamos and dedicated to our national security mission, but let's be honest. The vision that inspires young students to become scientists and spend years struggling toward a Ph.D. is not the promise of studying the effects of aging on nuclear weapons and then hiding their research results in top-secret files. But if they are given the opportunity to perform the science that at once contributes to nuclear defense *and* the next generation of fuel-cell-powered automobiles, they are eager to come. Energy solutions for the nation, recruitment of top scientists for national defense—it's a win-win situation.

In this issue, you can learn how concerns over nuclear winter contributed to our understanding of global climate change, and how underground testing of nuclear weapons may provide the technology to mitigate climate change, or how hydrogen bombs and rockets may lead to a transportation revolution that helps solve climate change once and for all. All are examples of how defense-related technologies were beaten into ploughshares.

— *Anthony Mancino*

WORKING WITH INDUSTRY

ChevronTexaco Alliance

Los Alamos National Laboratory and ChevronTexaco Corporation have signed an agreement to form the Alliance for Advanced Energy Solutions. Donald Paul, vice president and chief technology officer for ChevronTexaco, said "over a period of time, ChevronTexaco and Los Alamos have cooperated in a variety of projects, including radio frequency telemetry and sensor technology for collection and transmission of oil well data and acoustic interferometry and are now entering into a strategic alliance for increasing cooperation."

One way to reduce dependence on foreign oil and gas is to extract as much as possible from North American wells, but as easily accessible oil and gas reserves are depleted, the industry faces new challenges recovering resources from ever deeper and more hostile environments. Because current methods of retrieving downhole data are somewhat primitive, the industry could greatly benefit from Los Alamos's expertise in the physics of deep geological systems and in moving data from deep wells to the surface using advanced telemetry and improved sensor packages.

Photo courtesy of ChevronTexaco

ChevronTexaco and its partner, Transocean Inc., achieved an industry record when Transocean's drillship Discoverer Deep Seas spudded Tonga, the deepest well ever drilled in the U.S. Gulf of Mexico, at a total vertical depth of 31,824 feet.

Moving Superconducting Wire into the Marketplace

Los Alamos's Superconductivity Technology Center successfully transferred its patented superconducting wire technology to Superpower, Inc. in a two-year, $3.4M cooperative research and development agreement focused on scaling up the Laboratory's coated conductor technology. This collaboration recently demonstrated the commercial viability of high-temperature superconducting (HTS) wire by achieving over 100 amperes per centimeter width in a 100-meter length. This length is a key, enabling parameter for using HTS wire in device applications. Superpower anticipates full-scale wire production by 2006.

Ocean and Sea Ice Modeling in the High Desert

In the high and dry desert of northern New Mexico—7,500 feet above sea level and nearly 800 miles from the nearest coast—scientists are modeling the ocean and sea ice. It's all part of a greater effort to understand global climate change, which has emerged as a major driver of energy policy. If it weren't for the spectre of climate change, the U.S. could burn coal with abandon to produce electricity for decades to come. But even before fossil fuels were widely accepted as one cause of climate change, another form of energy conversion threatened to spark a climate catastrophe. Over 20 years ago, scientists began worrying that the awesome energy of $E=mc^2$, unleashed through nuclear war, could initiate nuclear winter.

In the summer of 1983, Nobel Laureate Hans Bethe, famous for his work on the Manhatttan project and for his theory of energy production in stars, was making his annual trip to Los Alamos National Laboratory. At that time, the media had been headlining the possibility of a nuclear winter resulting from the Cold War turning hot. The subject was introduced to the scientific community by the seminal TTAPS (Turco, Toon, Ackerman, Pollack, and Sagan) paper, published in *Science* in 1983. Carl Sagan carried the issue to the public media to push for reductions in the superpowers' nuclear arsenals. The subject was quickly engulfed in more political rhetoric than scientific investigation, and Hans Bethe was concerned that the subject was not receiving the critical analysis it deserved. He encouraged the management at Los Alamos to undertake an initiative to model nuclear winter scenarios. Bethe's influence was instrumental in establishing the modeling effort that would put Los Alamos "on the map" for climate modeling.

Los Alamos needed a climate expert to lead the nuclear winter modeling effort. The job naturally fell to Robert C. Malone, a physicist who had earned his Ph.D. in 1973 from Cornell with a thesis on the cooling rate of neutron stars. One of his thesis advisors had been, by coincidence, Hans Bethe. Bob Malone had been strongly influenced by the first Earth Day held in 1970 and brought his research interests from neutron stars down to earth. His interest was in climate modeling, but with no opportunities in that field during the mid-70's, he accepted a job at Los Alamos in the laser-fusion program. The possibility of producing limitless, cheap energy from seawater through fusion was the next best thing.

In 1978, the Director of Los Alamos's Theoretical Division, Peter Carruthers, was convinced that global warming was a significant energy-related issue and created a position at Los Alamos in global climate modeling. Malone seized the opportunity to return to his primary interest and got the climate modeling job. There was just one problem. As Malone recalled, "there was no expertise in climate modeling at Los Alamos (myself included)!" His first priority was to quickly learn the state of the art in climate modeling and get himself involved in something relevant. To that end, he spent the summer at the National Center for Atmospheric Research (NCAR) and established good working relationships with some of the top climate modelers in the country. The experience proved so valuable that Bob spent two months at NCAR each summer from 1979 to 1983. By then, the potential for program growth was looking bleak. Los Alamos's internal Institutional Supporting Research and Development Fund would not support the program to grow beyond one person, and external funding granted by the Department of Energy was pulled in the face of budget cuts. That's when Hans Bethe and nuclear winter arrived at Los Alamos.

Before 1983, getting funds for climate modeling at Los Alamos was a hard sell, but after the nuclear winter scare, the relevance of climate modeling to the Laboratory's primary mission was hard to deny. Institutional funding was increased and the Defense Nuclear Agency, responsible for coordinating all federal nuclear winter research efforts, also added funding after visiting Los Alamos to review the program. This enabled Bob Malone to focus solely on nuclear winter scenarios for the next 4 years and to bring in a radiative transfer expert, Larry Auer.

The pressure to succeed skyrocketed in January 1984 when Los Alamos Director Don Kerr wrote a 3-page letter to Frank Press, President of the National Academy of Sciences, in which he outlined the five major objectives of Los Alamos's climate modeling research plan:

- Construct models for nuclear war scenarios that will provide the three-dimensional source function for smoke and dust;
- Enhance the radiation model to treat absorption and scattering by aerosols;
- Construct physics modules to handle the transport and dispersion of aerosols by model-generated wind-fields and subgrid-scale turbulence;
- Incorporate a modern parameterization of vertical turbulent transport;
- Develop parameterizations for both wet and dry scavenging (particulate removal) of smoke and dust.

The letter stated that these tasks would be carried out over the next few years, but that pace was far too leisurely because NCAR and Lawrence Livermore National Laboratory (LLNL) already had a big head start. Furthermore, the National Academy of Sciences was planning a major symposium on Nuclear Winter in March 1985, and NCAR and LLNL were already on the agenda. Los Alamos was not. Malone felt that to succeed, Los Alamos had to participate in that symposium, or the Laboratory might as well drop the project because it would be too far behind to contribute anything original. The small Los Alamos team made steady progress but the workload was enormous. They had some but not all of the pieces needed to meet their research

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Manhattan Project pioneer and Nobel Laureate Hans Bethe was concerned that nuclear winter was not receiving the critical analysis it deserved. He encouraged the management at Los Alamos to undertake an initiative to model nuclear winter scenarios. That initiative started Los Alamos researchers down a road that eventually led to one of the most successful and widely used ocean and sea ice models in the world. Hans Bethe recently passed away on March 6th of this year at the age of 98.

In a large-scale exchange of nuclear weapons, smoke from resulting fires could shroud the Northern Hemisphere. (Globe graphic concept by Jon Lomberg, www.jonlomberg.com)

What is Nuclear Winter?

"Nuclear winter" was the name given to the potential climatic effects of a large-scale exchange of nuclear weapons. Those effects could include

- Dust, radioactivity, and various gases thrown into the atmosphere and transferred to distant parts of the globe;
- Plumes of smoke sent into the atmosphere from burning cities, forests, and grasslands;
- Daylight reduced to near darkness for days and to twilight for weeks;
- Temperature drops that don't return to normal for more than a year;
- Climate irregularities for years.

Along with the other catastrophic effects of the explosions, these nuclear winter conditions could lead to harvest failures and reduced wild plant growth causing famine for humans, livestock, and wild animals.

Source: Greene, Percival, and Ridge. Nuclear Winter: The Evidence and the Risks. *Polity Press: Cambridge, 1985.*

Robert C. Malone was the driving force behind climate modeling at Los Alamos from before the nuclear winter program to the development of the highly successful ocean and sea-ice models, POP and CICE. He earned a Ph.D. in theoretical physics from Cornell University in 1973 and initially came to Los Alamos to model laser-driven and magnetically confined plasmas for fusion research. He is now retired from Los Alamos National Laboratory.

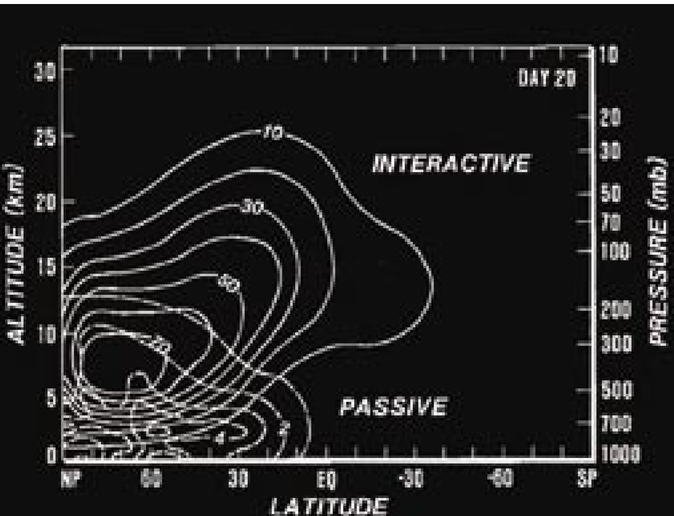
objectives, but the pieces had to be integrated into the full model, debugged, tested, and validated against whatever observational measurements could be found. After that, they would have to carry out simulations for a range of targeting scenarios at different seasons of the year, compare the "active smoke" cases with the normal climate, and interpret the results. More brainpower was critical, but funding for another full-time Ph.D. scientist didn't arrive until mid-1984, and qualified candidates were scarce. Enter Gary Glatzmaier.

Glatzmaier was a post-doc at Los Alamos who had just applied for a job at NCAR to work on their Community Climate Model (CCM). He initially approached Malone for advice on how to get a job at NCAR. But when Bob learned that Gary, while a graduate student, had written a three-dimensional, time-dependent, spherical solar dynamo model using spectral-transform methods–exactly the same methods used in CCM—he was sure he had the right person for Los Alamos's team. Gary was comfortable working with big codes and had a broad background in physics and hydrodynamics.

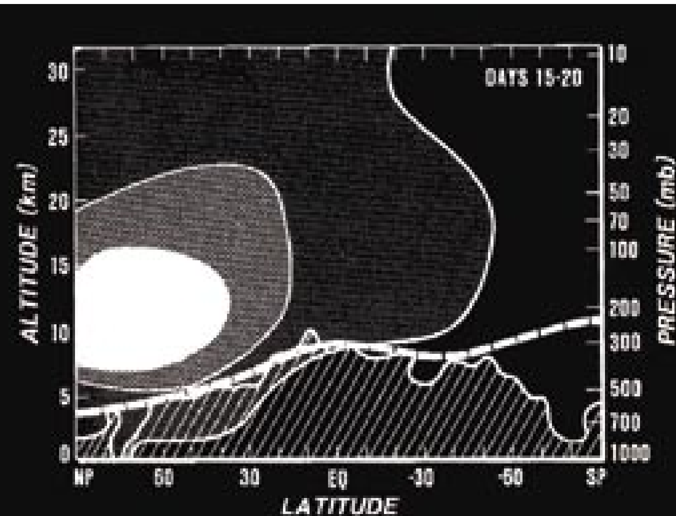
By October, the team had incorporated the horizontal smoke advection scheme and completed the first three objectives. Preliminary results, showing smoke transported in three dimensions and interacting with solar radiation, were so interesting that Brian Toon, Rich Turco, and Tom Ackerman (3 of the 5 authors of the TTAPS paper) came to Los Alamos. They were impressed and pleased because the Los Alamos model showed that under some circumstances solar heating of the smoke caused the tropopause to lower from its normal height (~10 km) to 5 km or lower. Solar heating in the smoke cloud also caused the smoke to rise above the lowered tropopause, thereby isolating it from scavenging by precipitation, which is confined below the lowered tropopause. This effect greatly increases the lifetime of the smoke. However, the predicted surface-temperature reductions were only about half as large as calculated by TTAPS in their one-dimensional model, but still very significant for large nuclear exchange scenarios. Turco and Toon told Carl Sagan about the model and results, and Sagan encouraged the National Academy of Sciences to invite Los Alamos to the March symposium.

On February 1, Bob Malone received an invitation and an apology from the National Academy of Sciences as well as a letter from Carl Sagan expressing his pleasure that Los Alamos would attend and present its results. The caller from the National Academy said they had not expected Los Alamos to have results so quickly. Of course, neither did anyone at Los Alamos, but after Glatzmaier joined the team, the rate of progress skyrocketed. Within just 7 months, the various bits and pieces were integrated into a model that met all the research objectives listed above except number 4. Their rapid success

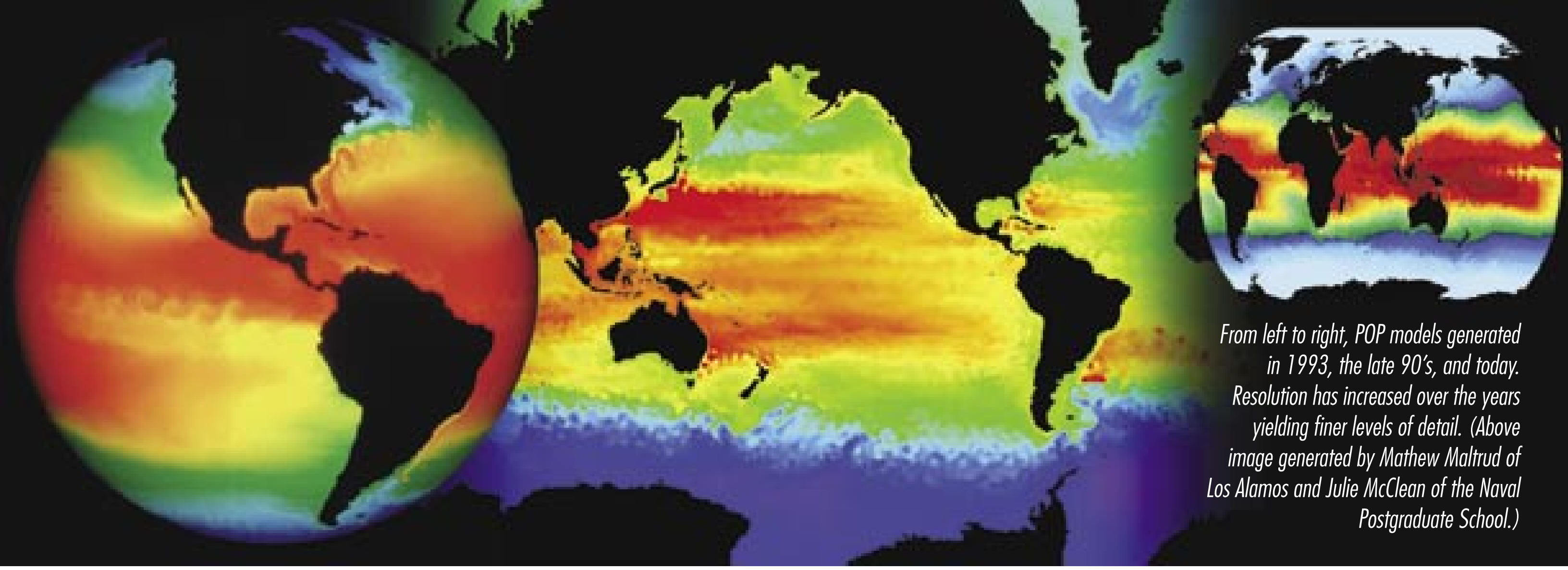
(Below and facing page) Models then and now—the graphs below represent results of nuclear winter modeling presented at the 1985 National Academy of Sciences conference. Images on the facing page show the evolution of ocean models at Los Alamos over the last 12 years.



The contour lines indicate how much smoke is left in the atmosphere 20 days after an exchange of nuclear weapons and how it is distributed over latitude and altitude.



The relative positions of the modified tropopause (dashed line), precipitation (slanted lines), and smoke distribution (dotted areas) 20 days after an exchange of nuclear weapons.



From left to right, POP models generated in 1993, the late 90's, and today. Resolution has increased over the years yielding finer levels of detail. (Above image generated by Mathew Maltrud of Los Alamos and Julie McClean of the Naval Postgraduate School.)

earned the nuclear winter modeling team a Los Alamos Distinguished Performance Award in 1985.
After the symposium, Steve Schneider of NCAR, during an interview with the *Washington Post*, graciously acknowledged that Los Alamos had the most complete model. Warren Washington, also of NCAR, included Los Alamos's work in his book *An Introduction to Three-Dimensional Climate Modeling*.

But despite Los Alamos's success and Department of Energy enthusiasm over the climate-modeling project, no funding increase came and in 1987, the Defense Nuclear Agency eliminated Los Alamos's funding. They felt that the global modeling aspect of nuclear winter was under control and money had to be directed to other nuclear winter projects. Despite this abrupt end to the project, nuclear winter had established Los Alamos's credibility in climate modeling. Malone and Glatzmaier were invited to give many talks on their work, even in Australia and New Zealand during trips paid for by those governments.

Still, without substantial funding from DOE, Los Alamos had no chance of competing with such giants as NCAR, the Max Planck Institute in Germany, the Hadley Centre in England, and the Geophysical Fluid Dynamics Laboratory at Princeton. These institutions each had a large technical staff, an official mandate, and a relatively stable budget to perform global atmospheric modeling. Atmospheric modeling was all but dead at Los Alamos, so the team moved on to other activities.

The outlook changed again, however, when the Department of Energy formed a committee, which included Bob Malone, to plan a new initiative to bring massively parallel computing to climate modeling. In 1991, the new program was dubbed CHAMMP (Computer Hardware, Advanced Mathematics, and Model Physics) and David Bader from Pacific Northwest National Laboratory was appointed to run it. Bader asked Malone to serve as Director of Model Development.

While CHAMMP was still in its formative stage, Malone made a crucial decision: if Los Alamos participated in CHAMMP, it would be in ocean modeling. While there was no future for Los Alamos in global atmospheric modeling, the picture was quite different in ocean modeling. At the time, there were only a few ocean models, and most of them were spin-offs from a 1969 model developed at the Geophysical Fluid Dynamics Laboratory (GFDL). Massively parallel computers, like the kind Los Alamos had to support its nuclear testing mission, were particularly well-suited to global ocean models because mesoscale eddies in the ocean are about ten times smaller (20-200 km) than eddies in the atmosphere. This means that ten times as many grid-points are required in both horizontal dimensions and, because the time step must be reduced by a factor of ten also, a factor of a thousand more computations is required.

Bob Malone hired Rick Smith and John Dukowicz whose expertise in nuclear physics and applied mathematics allowed them to completely reformulate the GFDL ocean model and incorporate new algorithms that would parallelize efficiently. Smith named the new code the "Parallel Ocean Program" or "POP." In 1992, Malone, Smith, and Dukowicz received a Los Alamos Distinguished Performance Award for POP, and in 1994 they won the Computerworld-Smithsonian Award in the Science category.

Over the past decade, Los Alamos's Climate, Ocean, and Sea-Ice Modeling (COSIM) Project grew to include a dozen full-time scientists and two post-docs of various backgrounds working on POP and CICE (the sea-ice model). Today it has a few less staff members than at its peak, but is still very active. Los Alamos is recognized as one of two major ocean modeling centers and is the leader in eddy-resolving ocean simulation. In sea-ice modeling, Los Alamos is perhaps the best in the world. NCAR's Community Climate System Modeling (CCSM) project has adopted POP and CICE for the ocean and sea-ice components. CCSM is available worldwide over the web and serves the university community in the U.S. making it the most widely used climate model in the world. As a result, Los Alamos's ocean and sea ice models will play an important role in our understanding of global climate change.

Funding for this work comes from DOE's Climate Change Prediction Program (CCPP) and Scientific Discovery through Advanced Computing (SciDAC) program, NASA, and the U.S. Navy.

— Robert Malone and Anthony Mancino

Hydrogen and Fuel Cells continued from page 5

Although technology development over the last two decades has been dramatic, PEM fuel cells are still too expensive and lack the power density, durability, and reliability to be economically and functionally competitive with conventional power conversion devices. Today's development program is oriented towards reducing costs (through materials development and substitution, performance improvement, and system simplification) and on increasing durability (by understanding performance degradation and life-limiting effects).

In 2003, the program direction shifted with the focus on PEM fuel cells running on pure hydrogen stored onboard the vehicle. This change in emphasis, embodied in the President's Freedom Cooperative Automotive Research and Fuel Initiative, resulted from a desire to minimize the country's dependence on imported oil while minimizing the environmental impacts of transportation. However, storing sufficient hydrogen onboard to enable a 350-mile driving range has been declared a "grand challenge." In April 2004, a Los Alamos-led collaboration focusing on chemical hydrogen storage was competitively awarded one of three DOE Hydrogen Storage Centers of Excellence.

Although the bulk of our funding comes from transportation programs, fuel cells are inherently scalable, and early market introductions are likely to occur in distributed power systems and portable electronics. A fuel cell sitting beside a home, using reformed natural gas or propane, would provide not only electricity, but also waste heat that could be captured and used for space heating and hot water production. But the first large-scale commercialization of fuel cells is likely to occur in the portable electronics market because fuel cell power systems offer greater energy densities than batteries. The miniature fuel cells being developed for these applications rely on a Los Alamos development that adapted and optimized the basic PEM technology to use dilute methanol as a high-energy-density hydrogen carrier.

Los Alamos is continuing to develop the next generation of fuel cells and related technologies and is facilitating technology transfer through publishing, licensing, student programs, direct training of industrial personnel, cooperative research and development agreements, and migration of technical staff and students to industry. The Laboratory has established the Institute for Hydrogen and Fuel Cell Research to facilitate internal collaboration and provide the outside world with access to our existing knowledge base, experts in the field, and state-of-the-art experimental and analytical capabilities. The Institute may also provide a magnet for regional economic development.

— Ken Stroh

Carbon Sequestration continued from page 7

significant impact on atmospheric CO_2 levels.

Storage of CO_2 in engineered geologic reservoirs poses significant scientific challenges, particularly when one considers the potential scale. For comparison, a typical large-scale enhanced oil recovery operation injects about 10 million tons of CO_2/year to displace hard-to-access oil reserves. Sequestering just 10% of U.S. emissions would require perhaps 50 such sites. One challenge for researchers will be to predict the performance of proposed geologic sites with confidence. These predictions require high-resolution characterization of reservoirs at sufficient depths to account for CO_2 re-distribution following injection. The cap rock will also require high-resolution characterization to determine the presence of any potential breaches such as faults and fractures. Once the site is well characterized, prediction of CO_2 fate will require a detailed understanding of the physical and chemical processes that result from the interactions between the CO_2, the groundwater or brine, and their reaction with the rocks (caused in part by the acidic nature of carbonated brines). A final complication, caused by the heterogeneity and complexity of natural systems, is an assessment of uncertainty.

While carbon sequestration is no easy challenge, Los Alamos scientists have faced similar complex geological problems before.

— George Guthrie and Anthony Mancino

Researchers Bridge Superconductivity Gap

University of California scientists at Los Alamos National Laboratory working with a researcher from Chonnam National University in South Korea have found that magnetic fluctuations appear to be responsible for superconductivity in a compound called plutonium-cobalt-pentagallium ($PuCoGa_5$). The discovery of this "unconventional superconductivity" may lead scientists to a whole new class of superconducting materials and toward the goal of eventually synthesizing "room-temperature" superconductors that would be the basis for the dissipation-less flow of electric current through power lines.

In research reported in the scientific journal *Nature*, Nicholas Curro and a team of researchers provide evidence of how magnetic fluctuations, rather than interactions mediated by tiny vibrations in the underlying crystal structure, may be responsible for the electron pairing that produces superconductivity in the mixture of plutonium, cobalt, and gallium.

Superconductivity is an unusual state of matter in which electrical current flows without resistance through a material as a result of the material's electrons acting in pairs. Since the discovery at Los Alamos of $PuCoGa_5$ roughly two years ago, a burning question has been whether the compound was just another garden-variety superconductor, a so-called s-wave superconductor, or an unconventional one that is mediated by magnetic fluctuations, a d-wave superconductor.

Although the temperatures at which superconductivity is observed are usually quite low, a handful of compounds like $PuCoGa_5$ have been found to possess superconductivity at temperatures warmer than minus 427 degrees Fahrenheit. Even though that temperature seems low, $PuCoGa_5$ possesses the highest superconducting transition temperature among actinide-based compounds found so far. This "unconventional superconductivity" suggests that $PuCoGa_5$ may be one of a very small handful of superconductors whose superconductivity actually derives from magnetic correlations.

The discovery is the result of collaboration between the Laboratory's Materials Science and Technology and Theoretical divisions. In addition to Curro, the team includes Tod Caldwell, Eric Bauer, Luis Morales, Yunkyu Bang, Matthias Graf, Alexander Balatsky, Joe Thompson, and John Sarrao.

$PuCoGa_5$ is an "unconventional superconductor" that may point the way to room-temperature superconductivity.

Durable Cathode Performance Demonstrated with Ultra-Low Platinum Loadings

Results from research in Los Alamos's Materials Science and Technology Division (MST) were recently highlighted to the Secretary of Energy by DOE Headquarters program management. Researchers have demonstrated 3,000-hour performance using ultra-low platinum (Pt) cathode loadings with catalysts developed by researchers from Brookhaven National Laboratory. Using other metals as supports (e.g., ruthenium and palladium) for which platinum has an affinity, it was possible to produce catalysts where platinum was deposited in sub-monolayer amounts. Thus, all platinum is at the surface available for the reaction.

A key question was if these kinds of catalysts would be stable for extended time periods. Recently we have demonstrated a cell with only 77 μg of Pt/cm^2 that operated at 600 mA/cm^2 for 3,000 hours. From this result, the performance was 0.24 g Pt/kW for the cathode. The 2005 DOE technical target is 0.6 g Precious Metal/ kW operating for 2,000 hours for the entire cell. The results of this research directly address two key barriers to the commercialization of fuel cells: durability and the high cost of platinum catalysts.

Los Alamos's Ecohydrology Team Participates in IAEA's Moisture Isotopes in the Biosphere and Atmosphere Program

Los Alamos's Ecohydrology Team, part of the Laboratory's Earth and Environmental Sciences Division (EES), has been invited to participate in the International Atomic Energy Association's Moisture Isotopes in the Biosphere and Atmosphere program (IAEA-MIBA). The MIBA program is focused on improving the quantification and understanding of the isotopic composition of water pools in the biosphere and atmosphere across the globe. Thirteen sites were chosen in North America to represent important biomes contributing to the continental isotopic budget of CO_2 and water vapor. Data collected from each site will be used to constrain the regional, continental, and global carbon and water budgets. MIBA conducts laboratory analyses of water samples collected bi-monthly from each site and is funded to continue for at least five years. Los Alamos was selected to participate in part because of its unique, real-time isotopic analysis of ecosystem carbon fluxes via EES's Tunable Diode Laser Absorption Spectroscopy Facility.

ENERGY RESOURCES

Publications, events, and websites for people interested in energy-related issues.

Publications

Roadmaps to the Energy Future

U.S. Photovoltaic Industry
http://www.seia.org/media/pdfs/pvroadmap.pdf

North American Natural Gas Vision
http://www2.nrcan.gc.ca/es/es/naewg/NANaturalGasVision_e.cfm

National Electric Delivery Technologies
http://www.energetics.com/electric.html

Carbon Sequestration (DOE)
http://fossil.energy.gov/programs/sequestration/publications/programplans/2004/SequestrationRoadmap4-29-04.pdf

Biomass Technologies
http://www.bioproducts-bioenergy.gov/pdfs/FinalBiomassRoadmap.pdf

National Hydrogen Energy
http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/national_h2_roadmap.pdf

2003 Electricity Technology
http://www.epri.com/roadmap/

Generation IV Nuclear Energy
http://gif.inel.gov/roadmap

Water Desalination/Purification
http://www.usbr.gov/pmts/water/desalroadmap.html

Oil Sands Technology (Canada)
http://www.acr-alberta.com/Projects/Oil_Sands_Technology_Roadmap/Oil_Sands_Technology_Roadmap.htm

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Events

Research Experience in Carbon Sequestration (RECS)

July 17-29, 2005
College of Santa Fe, Santa Fe, NM
http://www.recs.lanl.gov

RECS is a first-of-its-kind, summer research program for undergraduates, graduates, and early career professionals interested in technologies, theory, economics, and novel approaches to capturing CO_2 in geological settings. Experts from academia, industry, and government laboratories will present information on separation/capture, long-term storage, and monitoring/mitigation. Classroom and field research will be conducted at the College of Santa Fe and at field sites in the southwest. Details about the application procedure, tuition costs, and the program can be found at the website above.

Websites

EIA Country Analysis Briefs http://www.eia.doe.gov/emeu/cabs/contents.html
Up-to-date energy information for other nations and more.

Surf Your Watershed http://www.epa.gov/surf
Clickable map gets you detailed information for any watershed in the U.S. With 39% of freshwater withdrawals going to electricity production, water is an energy security issue.

World Nuclear Association http://www.world-nuclear.org
Comprehensive pro-nuclear resource from the organization "representing the technology, people and organisations of the global nuclear energy industry."

www.lanl.gov/energy

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