LOS ALAMOS ENERGY SECURITY

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Making Ethanol from Cellulose

Photo by Anthony Mancino

For each of us, this photo to the right may represent something very different—a summer walk or picnic in the country, that unfinished yard work you've been avoiding, or simply the beauty and variety of nature. But for a group of collaborating scientists from the University of Toledo and Los Alamos National Laboratory, this picture represents the most abundant renewable resource on earth, cellulose. Cellulose is what keeps trees standing and gives form to plants and their foliage. It shapes most of the natural living world around us. And if scientists can figure out an efficient way to convert it into ethanol, cellulose may also shape the direction of our energy future. A Los Alamos scientist is using novel neutron and X-ray diffraction techniques to peer into the nanostructure of cellulose to help engineer compounds that could unleash the potential of this vast energy resource (*continued on page 6*).

The Dawn of a New Era for Solar Energy

A nanotechnology breakthrough could double the efficiency of solar panels

The promise of clean, abundant solar energy has yet to be fulfilled largely because of inefficiencies in photovoltaic technology. Earth-bound cells have never exceeded 24.7% efficiency when converting the sun's photons into electrical current. But what if we could increase that efficiency by twice as much, or even more? Los Alamos researchers may have found a way to break the conversion efficiency barrier that has limited the widespread adoption of photovoltaics for decades. In addition to increasing the electrical output of solar cells, this breakthrough may also enable hydrogen production via photo-catalysis (*continued on page 4*).

Photo by Joshua E. Smith

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Los Alamos Energy Security, produced by Los Alamos National Laboratory's Science Program Office, 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

Diversifying the Nation's Energy Portfolio

Mary P. Neu
Associate Director
Chemistry, Life, and Earth Sciences Directorate

It is a challenging time for energy. News headlines and expensive stops at the filling station are frequent reminders that oil is finite and our environment is being altered by our energy use. Fortunately, research promises a brighter future—a shift to sustainable and environmentally benign technologies. Key to my optimism is the diversity of carbon-neutral or carbon-free options on scales that can make a real difference. Many of these energy possibilities are being advanced by science and innovation here at Los Alamos National Laboratory.

Solar power, the ultimate in renewable energy, has seen advances in recent years, but none so intriguing as carrier multiplication. With this single brilliant innovation, based on fundamental chemistry research, photovoltaic cells might jump 40% in efficiency. For energy storage combined with energy conversion, Los Alamos continues to be at the forefront of fuel cell development. In 15 years, our cars could be powered by fuel cells fueled with hydrogen stored using chemical methods such as catalytic release of hydrogen from ammonia borane.

Los Alamos is applying its decades of technical excellence in the geosciences for enhanced fossil fuel recovery and carbon capture which can extend our supplies of conventional oil and gas while reducing environmental impact. To reduce or remove our dependence on imported oil, we are working on alternative liquid fuels, including those from renewable biomass. Both ethanol from cellulose and diesel produced by algae can be enhanced through bioscience and bioengineering. Los Alamos is also a recognized leader in plasmas that make fuels burn more efficiently. Combustion products affect regional and global climate, and Los Alamos scientists are modeling these complex systems to understand how energy by-products, particularly aerosols, affect our atmosphere and climate.

Since its inception, Los Alamos has studied fission-based nuclear reactors, radionuclide separations, nuclear waste isolation, and other components of nuclear energy systems. With renewed national and global interest in nuclear energy, we are developing nuclear systems that minimize the risks in waste storage and disposition while enhancing chemical separations and fuel recycling. Nuclear fusion is advancing significantly through the international ITER project, and tritium systems engineered at Los Alamos are critical to ITER and the future of fusion energy. Soon our cars may be fueled by ethanol from converted biomass, our homes heated by solar energy from quantum dots, and our electricity supplied by fusion.

Most of the work described in this issue falls within the CLES Directorate, a new entity created by the Lab's new management, Los Alamos National Security, LLC. Composed of the Chemistry, Biosciences, and Earth and Environmental Sciences Divisions, this Directorate was formed in part to bring these fields together to perform research that can produce diverse energy options that consider the entire life cycle and impacts of energy systems. I hope these articles will leave you with the same sense of encouragement we feel. We believe that Los Alamos is helping to meet our energy challenges not with one voice but with a chorus of powerful energy technologies.

Lab Workshop Furthers International Hydrogen and Fuel Cell Partnership

Los Alamos National Laboratory Director Michael Anastasio greets Toshihiro Nikai, Japan's Minister of Economy, Trade and Industry during the Minister's visit to Los Alamos.

On August 27-30, 2006, Los Alamos National Laboratory hosted a workshop to bring together U.S. hydrogen and fuel cell researchers with representatives from Japan's New Energy Development Organization (NEDO) and Advanced Institute for Science and Technology (AIST). Japan and the United States are signatories to the International Partnership for the Hydrogen Economy, an agreement concluded among 17 countries.

The LANL-NEDO-AIST workshop focused on one of the critical remaining barriers to the Hydrogen Economy, namely fuel cell degradation. Japanese and U.S. researchers are working together to define the degradation problem, examine work done to date to solve it, and consider what remains to be done to remove this barrier. The workshop and future collaborative projects are explicitly confined to pre-competitive work and all research will be in the public domain.

Dr. Michio Hori of Japan's Daido Institute of Technology test drives Los Alamos' fuel-cell-powered scooter during the LANL-NEDO-AIST workshop.

Japanese Minister of Economy, Trade and Industry Visits Los Alamos for Energy Briefings

On August 14, 2006, the Japanese Minister of Economy, Trade and Industry (METI), Toshihiro Nikai, visited Los Alamos National Laboratory. In Japan, METI combines the functions of the U.S. Departments of Energy and Commerce, some of the Treasury Department, and the U.S. Trade Representative's office in the White House. Minister Nikai requested briefings on the Lab's work in fuel cells, civilian nuclear power, nuclear nonproliferation, and space science. The Minister and his delegation also toured the Laboratory's Fuel Cell Facility. Japan faces many of the same energy security issues as the U.S. but without our stocks of coal and natural gas to rely on. Los Alamos has collaborated with Japanese institutions before and hopes this visit will lead to further partnerships that strengthen the energy security of both nations.

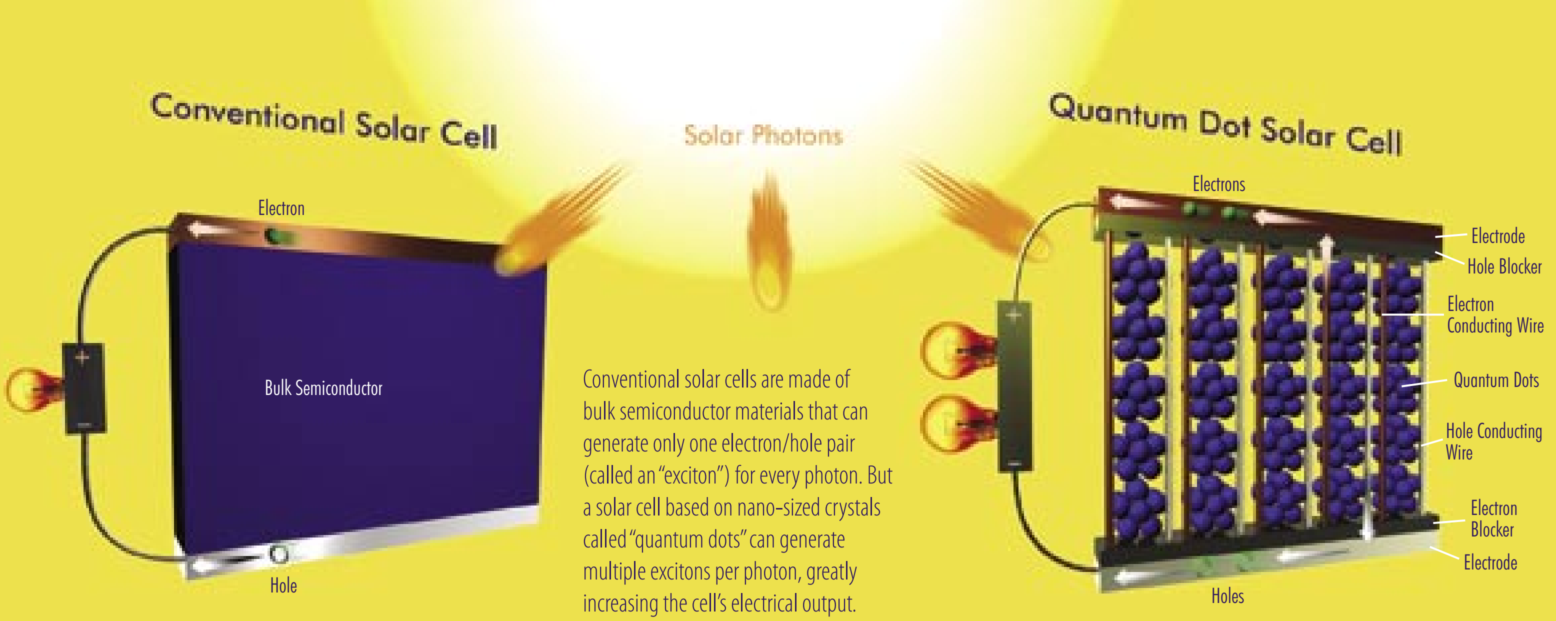
Carrier Multiplication and Quantum Dots

Photovoltaic panels used for converting solar energy into electrical current are made of semiconducting crystals with added impurities that encourage the crystal structures to more readily mobilize their electrons. When photons of sufficient energy strike a photovoltaic device, they knock electrons free and set them in motion as electrical current. The moving electron and the vacant hole left in its former position are together called an “exciton.” The problem is that one photon of sunlight has always produced one, and only one, exciton—until now.

The amount of photon energy required to release an electron in a semiconductor is known as the “energy gap.” If the photon energy exceeds the energy gap, the excess is wasted as heat. This physical limitation has always imposed a theoretical conversion efficiency limit of 30%. For nearly half a century, scientists have searched for materials that could transcend this limit, but none—including the conventional solar-cell materials like silicon and germanium—have shown any tendency to produce more electrical current within the range of the solar energy spectrum.

A breakthrough occurred in 2004 when researchers from Los Alamos National Laboratory’s Softmatter Nanotechnology and Advanced Spectroscopy Team discovered that nano-sized semiconductor particles of lead selenide (PbSe) could produce two or more excitons from a single photon. This phenomenon, known as “carrier multiplication,” relies on the unique quantum mechanical behavior of nano-sized crystals. In fact, more recent experiments duplicating the results with different nanocrystalline compounds suggest that the size is more important than the composition of the crystal. While the exact mechanism is still a matter of scientific debate, carrier multiplication works because these nanocrystals, called “quantum dots,” produce very strong electron-to-electron interactions by forcing the interacting charges to stay in close, nanoscale proximity to each other. So when a quantum dot absorbs a photon possessing energy in excess of the energy gap, the newly energized electron collides with a nearby bound electron and sets it free, which results in more electrical current.

Carrier multiplication seems to be limited only by the law of energy conservation (i.e., energy is neither created nor destroyed, but it can change its form). Since you can’t get something from nothing, carrier multiplication can only mobilize two electrons if the absorbed photon has more than twice the energy gap. In



Conventional solar cells are made of bulk semiconductor materials that can generate only one electron/hole pair (called an "exciton") for every photon. But a solar cell based on nano-sized crystals called "quantum dots" can generate multiple excitons per photon, greatly increasing the cell's electrical output.

Anthony Mancino

theory, only twice as much should be required, but experiments have shown that a little more is actually needed. Los Alamos researchers have recently generated seven excitons from one photon with 7.8 energy gaps.

Based on experimental data, the Los Alamos team believes it's possible to create a solar panel with a power conversion efficiency of 42%, so why hasn't industry begun to manufacture these panels? A significant technical challenge still prevents practical application of carrier multiplication. The excitons in quantum dots are so short-lived, lasting only trillionths of a second, that they settle down before they can be captured in a current-carrying circuit. The Los Alamos team is collaborating with the University of Texas at Dallas on a prototype made of lead selenide quantum dots blended with a conductive polymer that may help solve the problem. Other challenges include poor electronic conductivity in nanocrystal solids, photo-corrosion issues, and the toxicity of materials used in the study of carrier multiplication. Researchers at Los Alamos and others in the field are working to address these problems.

In addition to enabling a two-fold increase in photovoltaic efficiency, carrier multiplication could also improve the performance of photoelectrolytic devices used to drive chemical reactions, such as the production of hydrogen or other high-energy fuels and chemicals. There has been much talk about the promise of hydrogen fuel cells and a hydrogen economy, but hydrogen cannot be freely mined from nature. It must be stripped from hydrogen-containing compounds, such as water or hydrocarbon (fossil) fuels. The cost and environmental impact of the energy required to do this stripping makes hydrogen less attractive than it first appears. However, the ability to produce clean hydrogen from water using solar power could make hydrogen fuel live up to its "green" reputation. The production of hydrogen by photo-catalytic water splitting requires four electrons for each water molecule. Since carrier multiplication energizes multiple electrons per photon, it may be the key to achieving the efficiency that would make this process viable. Once the technical hurdles are overcome, carrier multiplication using quantum dots has the potential to greatly impact national energy security.

Carrier multiplication research at Los Alamos is supported by the Chemical Sciences, Biosciences, and Geosciences Division of the Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy and by Los Alamos LDRD funds.

— Victor I. Klimov, Richard D. Schaller, and Anthony Mancino

Victor Klimov (left) and Richard Schaller operate an ultrafast laser system used to study carrier multiplication in quantum dots. Klimov and Schaller are members of the Softmatter Nanotechnology and Advanced Spectroscopy Team in Los Alamos' Chemistry Division. Learn more at the team's web site: http://quantumdot.lanl.gov. (Photo by LeRoy N. Sanchez)

Cellulosic Bioethanol

A Los Alamos scientist is helping to unlock the potential of this abundant, domestic, renewable energy resource

One of the most important energy security and environmental goals over the next few years will be to develop biomass as a raw material for bioethanol fuels. A recent report prepared by Oak Ridge National Laboratory found that land resources in the United States could produce over a billion tons of biomass per year. That's enough to displace 30 percent of the nation's present petroleum consumption. The U.S. ethanol industry is growing rapidly, but the majority of ethanol is made from the starch (that is, the edible parts) of grains such as corn and sorghum. Starches are only a minute fraction of biomass resources. The far greater share, cellulosic biomass, is currently unused because it resists industrial attempts to break it down to a simple sugar—a necessary first step in the fermentation of bioethanol (see box on facing page).

Ionic Liquids

A team of researchers from the University of Toledo and Los Alamos National Laboratory are trying to solve this problem through the use of ionic liquids. Ionic liquids are salts that are liquid near room temperature. Salt can be formed by mixing acids and bases together so that they form a compound between two atoms or two chemical groups, one negatively charged called an anion, and another positively charged called a cation. Because ionic liquids have a low melting point and are made of electrically charged cations and anions, they are better than more common liquids, such as water, at pulling apart and dissolving solids. Ionic liquids don't emit vapors as do common organic solvents, so they are more environmentally friendly. They are versatile solvents because their chemical structures can

Photo by Anthony Mancino

be engineered or tuned to dissolve a variety of compounds. In ground breaking experiments, two members of the team, Connie Schall and Sasidhar Varanasi from the Chemical Engineering Department at Toledo, have found that pre-treating cellulose with certain ionic liquids can break down the crystal structure into individual chains allowing them to degrade into sugar molecules more easily with subsequent use of enzymes called cellulases. In fact, the rate of glucose production in the pre-treated cellulose increased by a factor of almost 100. Now, with the help of Jared Anderson from Toledo's Chemistry Department, Schall and Varanasi are working to engineer the chemical structure of the ionic liquids to efficiently convert cellulose into simple sugars for bioethanol production. However, to understand how the cations and anions affect the biomass, they must be able to "see" at the atomic and molecular level.

"Corn ethanol, though valuable, can play only a limited role, because its ability to displace gasoline is modest at best. But cellulosic ethanol, should it fulfill its promise, would help to wean us of our petroleum dependence."

~ Alan Greenspan

Neutron and X-ray Diffraction at Los Alamos National Laboratory

That's where Paul Langan, a scientist in Los Alamos' Bioscience Division, is helping. Langan has been developing novel neutron and X-ray diffraction techniques for studying the structures of fibrous materials, and it looks like those techniques may play an important part in the development of ionic liquids. The structure and properties of cellulosic biomass are incredibly complex. Cellulose is perhaps the most studied polymer in the world, and researchers have been trying to see its structure using X-ray diffraction methods for almost a century. Two decades ago, scientists with the U.S. Department of Agriculture surprised the research community when they discovered that cellulose is composed of not one but two crystal forms which they called $I\alpha$ and $I\beta$. That means cellulose chains can densely pack together in two very different ways. We now know that the amount of $I\alpha$ and $I\beta$ vary from species to species. Langan, together with researchers from the Centre de Recherches sur les Macromolécules Végétales in Grenoble, France, the University of Tokyo, and Kyoto University, isolated samples of the $I\alpha$ and $I\beta$ forms and determined their detailed atomic structures using state-of-the-art neutron and synchrotron X-ray radiation facilities. The results were important enough to warrant a review in the leading scientific journal, *Nature*. The team also used these diffraction techniques, together with a number of other spectroscopic techniques, to characterize the structure of cellulose during and after various industrial processes that change $I\alpha$ and $I\beta$ to even more complex crystal forms such as cellulose II and cellulose III. The insight gained by these and future experiments will be critical to engineering ionic liquids that degrade cellulosic biomass.

With demand for transportation fuels rising and political instability in

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Starch vs. Cellulose

Corn

Wheat

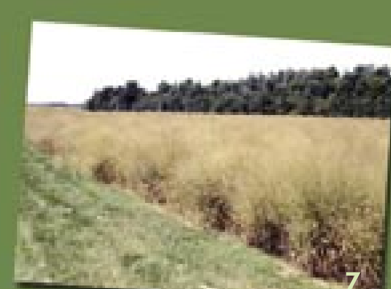
Sorghum

Today, most ethanol is made from starch, the edible portion of grains such as corn, wheat, and sorghum (left). Cellulose is the fibrous, woody, and generally inedible portion of plant matter. As such, it is usually a farm waste, like cornstalks, but also includes fast-growing trees, grasses, and waste products like paper and wood chips (right). So why use valuable food to produce fuel when we could do it with useless bio-junk? It turns out that the ethanol industry hasn't been much more efficient than our human digestive systems when it comes to breaking down the huge polymer chains that give cellulose its structure. To derive fuels from biomass, the raw material must first be broken down into simple sugars which are fed to microorganisms (yeast or bacteria) that convert the sugars into ethanol. The cellulose, hemicellulose, and lignin that make up cellulosic biomass consist of complex, closely packed polymer chains of molecules that don't easily break down into simple sugars. Starch, like cellulose, is a polymer of glucose but the glucose rings are linked differently and the polymer chains are packed into crystalline granules that readily break down into usable sugars. But corn and other starches and sugars represent only a small fraction of biomass. The challenge is to find a way to break the much larger, unused share of plant resources—cellulosic biomass—into simple sugars without using more energy than the resulting ethanol would yield.

Photos courtesy of USDA NRCS.

Corn stalks (farm waste)

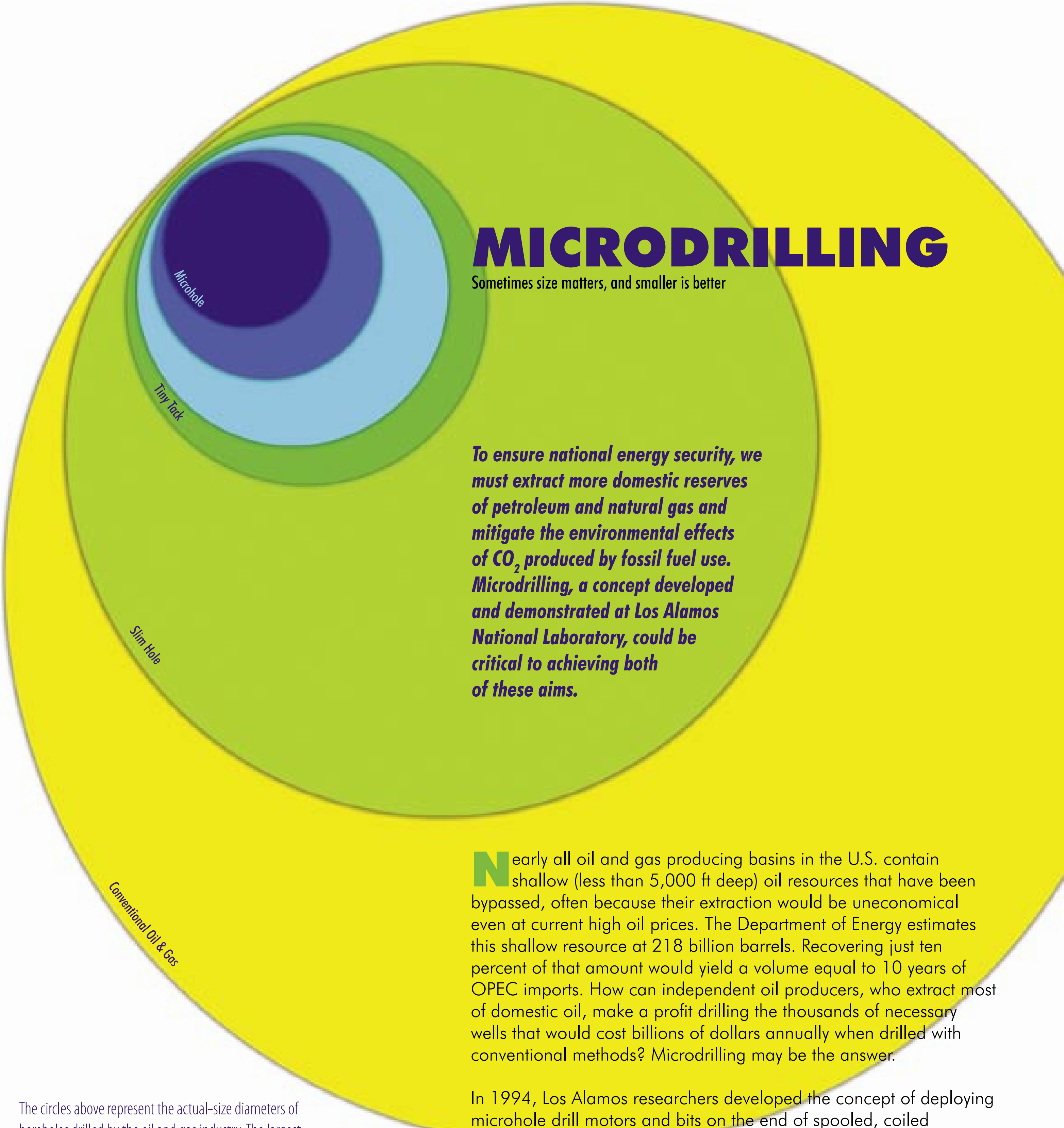
Forest waste



Switchgrass

MICRODRILLING

Sometimes size matters, and smaller is better



To ensure national energy security, we must extract more domestic reserves of petroleum and natural gas and mitigate the environmental effects of CO_2 produced by fossil fuel use. Microdrilling, a concept developed and demonstrated at Los Alamos National Laboratory, could be critical to achieving both of these aims.

Nearly all oil and gas producing basins in the U.S. contain shallow (less than 5,000 ft deep) oil resources that have been bypassed, often because their extraction would be uneconomical even at current high oil prices. The Department of Energy estimates this shallow resource at 218 billion barrels. Recovering just ten percent of that amount would yield a volume equal to 10 years of OPEC imports. How can independent oil producers, who extract most of domestic oil, make a profit drilling the thousands of necessary wells that would cost billions of dollars annually when drilled with conventional methods? Microdrilling may be the answer.

In 1994, Los Alamos researchers developed the concept of deploying microhole drill motors and bits on the end of spooled, coiled tubing carried on a relatively small trailer that could be pulled by a standard pickup truck. The coiled tubing replaces the segmented, large-diameter drill pipes used in conventional drilling. The system can drill holes as small as 1.25″ in diameter—7 times smaller than a conventional 8.75″ wellbore. By 1999, Los Alamos proved the feasibility of the concept by drilling holes up to 700 feet deep in field experiments. The Department of Energy quickly recognized the promise of microhole technology and invested millions of dollars in R&D projects to help make the technology commercially viable.

The circles above represent the actual-size diameters of boreholes drilled by the oil and gas industry. The largest of these (yellow) is a conventional 8.75″ hole, which is the industry standard. The three smallest holes (blue) are microholes with the smallest a mere 1.25 inches.

The Advantages of Treading Lightly

The advantages of microdrilling were clear. The small microdrilling system occupies a space roughly 20 times smaller than a conventional rig. The smaller footprint and decreased weight greatly reduces environmental impact, which is particularly important when operating in ecologically sensitive areas. Microdrilling units are easier to transport and require less equipment, materials, and manpower. Smaller boreholes mean less waste (drill cuttings and waste fluids) and reduced disposal costs. Together, these factors add up to a 60% cost reduction.

Data Collection

The ability to drill inexpensive wells also allows deployment of a larger number of data collection devices under better conditions than ever before. These devices will lead to greatly enhanced oil & gas production and to safer and more effective geologic sequestration of CO_2. Seismic and other geophysical instruments allow the industry to image and study areas of potential production, but such data gathering is currently limited by the environmental impact and cost of digging exploratory wells in which the instrumentation must be placed. Instruments are sometimes placed in existing production wells, but that requires shutting down production, and the data sampling location may not be optimal. In contrast, inexpensive microholes allow the drilling of numerous exploratory wells in optimal, low-noise locations. The resulting improvement in subsurface characterization will lead to discovery of more overlooked resources and increased production efficiency.

The microhole drilling system is shown here in central Nevada drilling cased 1.25-inch diameter microholes for emplacement of seismic instrumentation. The tan equipment (right) is the coiled tube drilling rig, the blue is a mud conditioning system, and the yellow is a PVC casing grouting system.

Geologic CO_2 Sequestration

Similarly, geologic sequestration (the storage of anthropogenic CO_2 emissions in geologic reservoirs) will rely on adequate monitoring and measurement. CO_2 containment can only be ensured by measuring chemical and physical processes in subsurface rock surrounding the CO_2 reservoirs. Advances in

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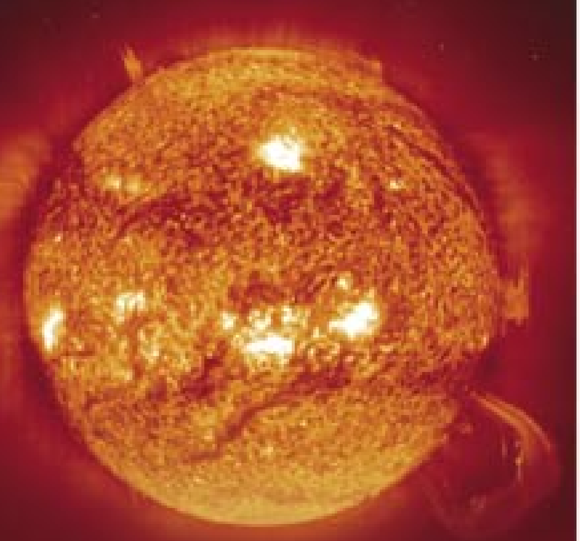
Comparison of waste produced from drilling a 1,000-foot hole. Conventional drilling of an 8.75" diameter hole requires the disposal of 77 barrels of drill cuttings and circulating fluid as opposed to a mere 2 barrels with the Los Alamos microdrilling system.



ITER

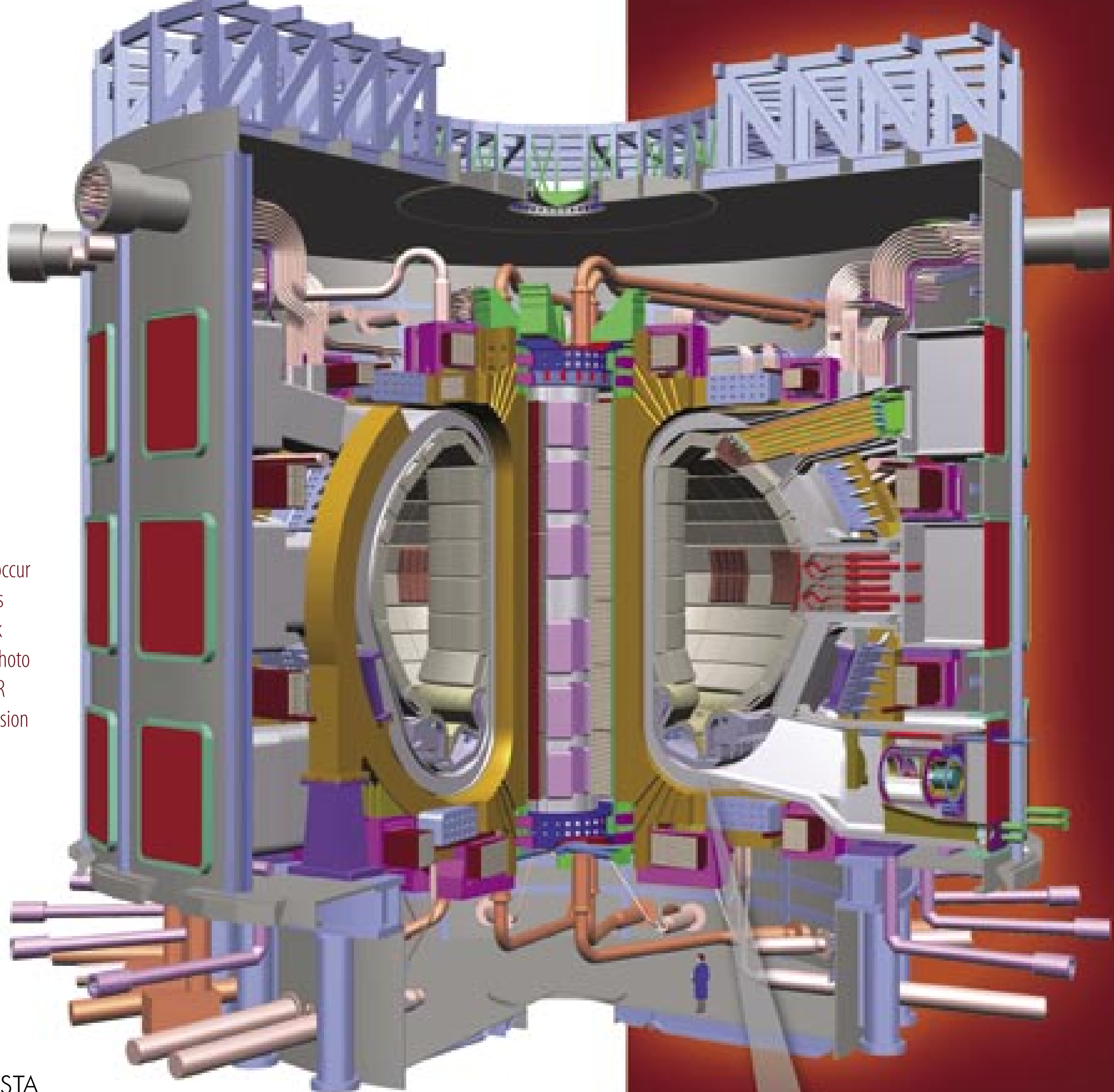
The Way to Fusion Energy

Fusion, the process that powers the sun, could one day provide a limitless supply of energy with no greenhouse gas emissions and minimal long-lived radioactive waste. However, to make fusion happen on earth, hydrogen atoms must be heated to 100 million degrees, forming a plasma which must be magnetically confined long enough for fusion to occur. While difficult to achieve, great progress has been made. Current experiments have reached a condition called "break even" (that is, the fusion energy generated is equal to the energy required to run the reactor). An international collaboration called ITER ("the way" in Latin) is finalizing an agreement to build a next-generation fusion reactor in Cadarache, France, designed to reach ten times the break even point or better. Los Alamos is slated to play a key role in the United States' contribution.

For 21 years, Los Alamos ran the Tritium Systems Test Assembly (TSTA) which was designed to demonstrate that deuterium-tritium fuel could be safely and efficiently processed for fusion energy production. The 1987 newsbulletin article above reports on successful experiments at the TSTA. The two photos show the inside and outside of Los Alamos' TSTA facility.

The fuels needed for fusion are deuterium, plentiful in ordinary water, and tritium, which can be produced from the abundant element, lithium. Only five percent or less of this deuterium-tritium (DT) fuel is consumed (fused) as it passes through the ITER plasma chamber. Because the unburned DT fuel is both hazardous and expensive, it can't be merely discarded. Instead, it must be processed and prepared for re-injection into the reactor together with make-up DT fuel. This process requires a tritium plant like the one Los Alamos operated for 21 years.

From 1982 to 2003, Los Alamos ran a fusion fuel processing pilot plant called the Tritium Systems Test Assembly (TSTA). It included all tritium plant subsystems in an interconnected loop and demonstrated that DT fuel could be effectively and safely recycled as needed for fusion. Los Alamos' TSTA, which was recently decommissioned, was approximately one



Cutaway design illustration of the ITER fusion reactor. The fusion reaction will occur in the torus-shaped chamber, known as a "tokamak," in the center. The tokamak segment and workman shown in the photo (below right) show the scale of the ITER reactor. (Images published with permission of ITER.)

tenth the scale of ITER. Los Alamos National Laboratory was a key developer of the specialized technologies needed for the tritium plant. The technology developed at TSTA was successfully fielded in the 1990's at the Princeton Plasma Physics Laboratory which for a time held the world record for magnetically confined fusion power. Based on this experience, the U.S. has been assigned responsibility for supplying the Tokamak Exhaust Processing (TEP) system for the ITER Tritium Plant. ("Tokamak" is a Russian acronym which refers to the magnetic, torus-shaped chamber in which the plasma is generated). The TEP system must accept gases from the tokamak exhaust and from other sources and remove impurities. In general, these gases will consist mostly of DT. The TEP must purify this DT, but it must also recover the DT from impurities that grow into the gas during its journey through the fusion reactor's thermonuclear environment. Such impurities include water and methane.

Savannah River National Laboratory (together with Washington Savannah River Company) recently constructed large, weapons-related tritium processing facilities. Since Savannah River's fabrication and procurement capabilities complement Los Alamos' experience with R&D, design, and testing of fusion tritium processing systems, the two labs will work together to provide ITER's exhaust processing system. The system must be finished, tested, and delivered to Cadarache by 2014.

While considerable tritium processing technology is available, delivery of a successful TEP system will be a challenge. Compared to current and previously operated systems, ITER's TEP will have to operate with a flow rate and tritium inventory increased by a factor of 10, and it will have to deliver a specified product about 10 times

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ACSi

Transmission electron micrograph showing a cross-section of ACSi film and underlying buffer layers on metal tape.

Aligned-Crystalline-Silicon Films for Solar Cells

Los Alamos' research in carrier multiplication and quantum dots (see page 4) may help solar cells of the future achieve double efficiency. But Los Alamos is also developing a way to manufacture today's solar cells less expensively without sacrificing efficiencies already gained.

Silicon is by far the most-widely used material in a booming solar cell market that is growing by more than 30% per year. However, with increasing silicon feedstock and wafer costs, and competition from other renewable energy resources, the solar power industry needs alternative technologies that will reduce materials and fabrication costs while retaining high solar cell conversion efficiency.

The two dominant emerging technologies are silicon-ribbon wafers and silicon films (both amorphous and multicrystalline). The first of these, silicon-ribbon wafers, aims to achieve a modest reduction in fabrication costs by continuously pulling 200-micron-thick Si sheets from a melt while keeping solar cell conversion efficiency close to that of conventional bulk crystalline Si. The second technology, amorphous and multicrystalline Si films, aims to achieve large reductions in materials and fabrication costs by using 1 to 30 micron-thick Si films on inexpensive substrates while tolerating reductions in efficiency. Despite recent advances, these Si film technologies force buyers to sacrifice efficiency for cost savings. The choice with these two technologies, as with most manufactured products, is either high cost and high performance or low cost and low performance.

Using ion-beam-assisted-deposition (iBeam) techniques developed in the Lab's Superconductivity Technology Center, Los Alamos researchers may have found a way to offer the long sought after third choice—low cost and high performance. The technology, dubbed "ACSi" (Aligned-Crystalline-Silicon), allows manufacturers to deposit a buffer layer on low-cost substrates, such as metal alloy tapes. The buffer layer serves as a template for the growth of ACSi films. The ACSi method combines the cost advantage of Si films with the high efficiency of Si ribbons and bulk crystalline Si.

ACSi has generated a lot of interest among the research community and industry. Los Alamos hopes to fabricate a first generation ACSi solar cell prototype and bring the technology to market through industry partnerships.

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Microdrilling, continued from page 9

electronics and sensor miniaturization in the past decade have made new instrument packages with small diameters possible and increasingly affordable. These instrument packages, however, are poorly suited for large boreholes. Without microdrilling, it would be difficult to deploy sufficient instrumentation to monitor sequestration processes.

Los Alamos National Laboratory is currently collaborating with Lawrence Berkeley National Laboratory to use time-lapse vertical seismic imaging to characterize fluid migration during CO_2 injection. Last year, Berkeley deployed a 20-level hydrophone and geophone string in a 750-ft microhole drilled by Los Alamos at the Rocky Mountain Oil Testing Center at Teapot Dome, Wyoming. The DOE's National Energy Technology Laboratory funds this work. Los Alamos' microdrilling system, which can now drill to 1,500 feet, also serves as a test platform for new technologies that may advance microdrilling even further and lead to a sea-change in the way U.S. industry approaches the fossil fuel cycle, from exploration to containment of CO_2 emissions.

— *Anthony Mancino*

Cellulosic Bioethanol, continued from page 7

petroleum producing regions, it's hard to overstate the importance of cellulosic bioethanol to the environment and to our energy security. We are inundated with the necessary resources to make it right here at home. With agricultural wastes assuming a new value, farmers could now sell two cash crops where before there was only one. And while all bioethanol burns cleaner than fossil fuels, studies have shown that cellulosic bioethanol is even cleaner than grain-based ethanol. The multidisciplinary expertise and unique facilities at Los Alamos and collaborating institutions are helping to unlock the potential of this vast energy resource.

— *Paul Langan and Anthony Mancino*

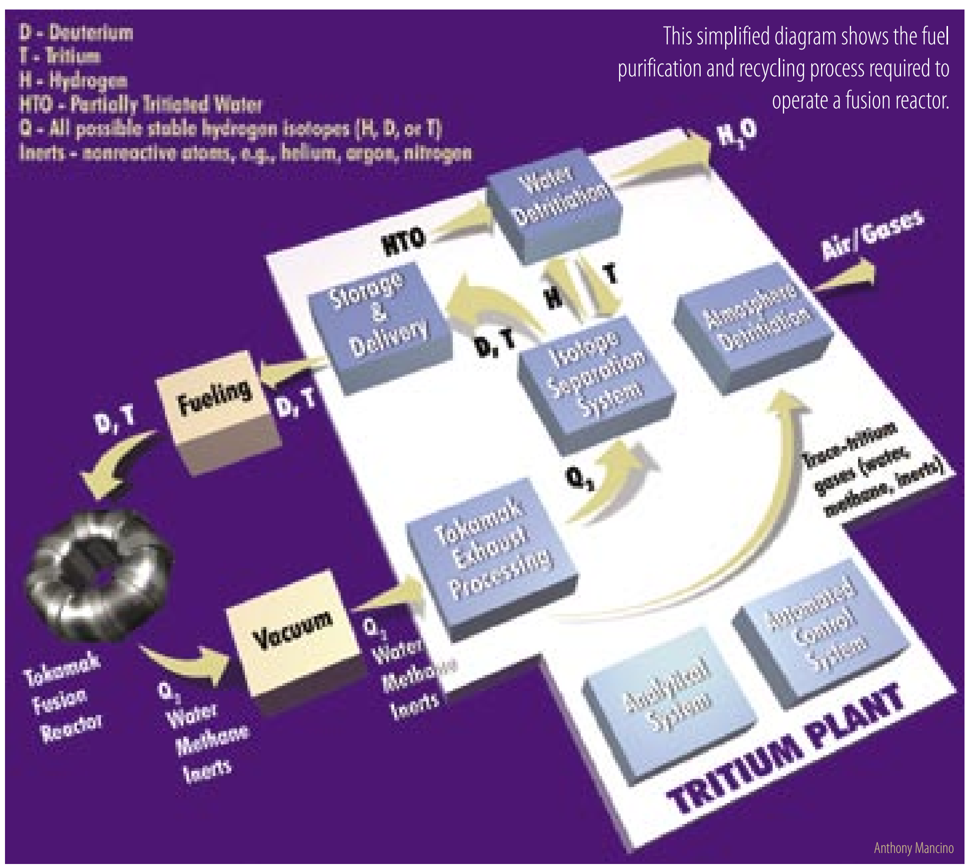
ITER, continued from page 11

faster. These scale-up considerations are perhaps the largest technical risks associated with the project. These risks will be addressed with state-of-the-art computer modeling and system testing at the end of the project.

Los Alamos' ITER-related chemical processing work will primarily be performed in the Chemistry Division's Chemical Sciences and Engineering group. Scott Willms, Craig Taylor, Bryan Carlson, David Dogruel, and Matt Cover will be the key technical staff.

The international agreement to build ITER is scheduled to be formalized in November 2006. Partners include the U.S., Europe, Japan, South Korea, China, Russia, and India. ITER will be a big step in demonstrating that fusion can one day safely and cleanly meet the world's increasing energy needs.

— *Scott Willms*



This simplified diagram shows the fuel purification and recycling process required to operate a fusion reactor.

Anthony Mancino

Effects of Megacity Soot on Global Warming

A team of Los Alamos scientists spent a month gathering data in Mexico City where they examined the chemical and physical transformations of gases and aerosols in the polluted outflow from the Mexico City metropolitan area. With a population of 25 million, Mexico City is North America's largest city, what scientists are calling a "megacity." As such, it provides an excellent testing ground for understanding the regional and global impacts of increasing urbanization.

The Los Alamos team performed measurements of the radiative and optical properties of soot using a state-of-the-art Los Alamos-developed field-deployable photo-acoustic instrument. They also provided the only measurements of molecular hydrogen in Mexico City. These measurements provide a unique data set for quantifying Mexico City's atmospheric soot, which is little more than fine carbon particles.

Soot is produced by diesel combustion, burning of biomass, and power plants. Soot-containing aerosols absorb solar radiation, which causes atmospheric warming. However, soot's warming potential is determined by complex interactions with other anthropogenic aerosols, such as sulfate and organics, which by scattering solar radiation tend to offset the warming caused by pure soot.

The data are already beginning to tell the story of Mexico City's environment. A very regular daily profile has emerged revealing peak concentrations of both hydrogen and soot in early morning caused by the high traffic volume and pollution close to the ground. The instrumentation recorded levels of hydrogen at 5 parts per million, which is 10 times more than normal background levels. Scientists theorize that most of the hydrogen is coming from automobiles.

The Los Alamos team will now integrate the net radiative effects of all pollutants: carbon dioxide, aerosols, and ozone. Observed changes in the amount of light that reaches the ground in Mexico City could help determine the global warming potential of a megacity.

The Los Alamos work was part of the MILAGRO (Megacity Initiative: Local and Global Research Observations) campaign. The scientists studied Mexico City and its surrounding areas as part of a larger effort to understand the local, regional, and global impacts of air pollution from a megacity. MILAGRO, in turn, is part of the Megacity Impacts on Regional and Global Environments (MIRAGE) project, a collaboration made up of scientists from more than 60 institutions, including the U.S. Department of Energy, the National Center for Atmospheric Research, the Molina Center on Energy and the Environment, and NASA. More information about the Laboratory's work in this area is available online at http://aerosols.lanl.gov.

New Borane Chemistry for Chemical Hydrogen Storage

Fran Stephens, Richard Keaton, and Tom Baker, scientists with Los Alamos' Inorganic, Isotope, and Actinide Chemistry Group, have developed new catalytic processes for releasing hydrogen from ammonia-borane (AB). AB is a promising candidate for storing hydrogen on board vehicles for use in fuel cells. Its storage capacity is 19.6 wt% hydrogen if all the hydrogen could be released under moderate conditions, which is more than twice DOE's most ambitious weight capacity target for vehicular hydrogen storage. However, the chemistry of AB is complicated and, until now, hydrogen release has required either harsh thermal conditions or prolonged exposure to precious metal (rhodium) catalysts. In work done at LANL, in collaboration with other institutional partners in the Center of Excellence for Chemical Hydrogen Storage (funded by the DOE EERE Hydrogen Program), new catalytic hydrogen release reactions using protic and Lewis acids, or non-precious metal complexes, have been discovered. Once fully optimized, these catalytic reactions could enable widespread use of AB as a hydrogen storage material.

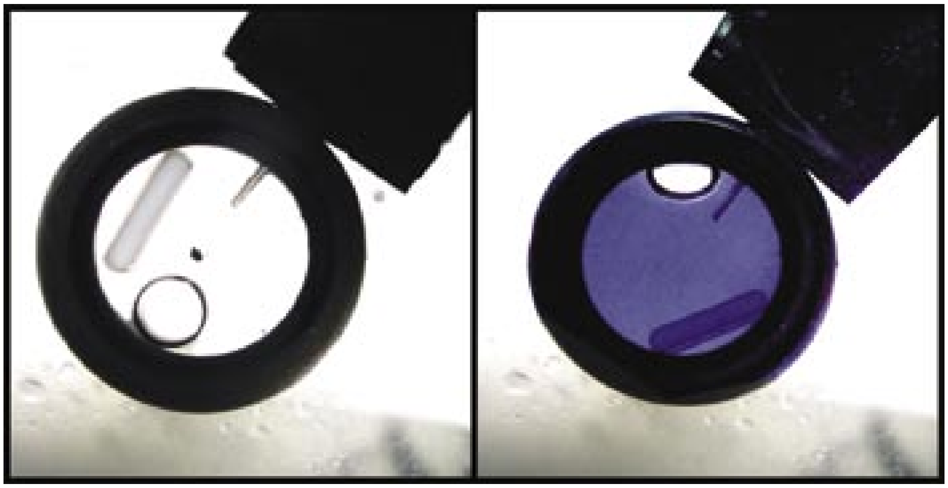
To make AB feasible for automotive hydrogen storage, however, we must discover an energy-efficient way to regenerate AB from spent (dehydrogenated) material. Los Alamos chemists, Dan Schwarz and Dave Thorn, have identified key reactions that may lead to a new route for forming AB, using reducing agents comparable to hydrogen itself and reaction temperatures under 200°C. By avoiding very high temperature conditions and sodium-metal reductions, which are typical of borane synthetic routes currently practiced, their work promises to make AB with almost ideal thermodynamic energy efficiency.

Los Alamos Researchers Patent New Materials that Could Lead to Energy-Efficient Windows

Ionic liquids represent a new set of solvents with immense promise for the development of new chemistry and new materials. Ionic liquid attributes can include temperature stability, a wide electrochemical window, conductivity, and unique solubility. Researchers with the Materials Chemistry Group within Los Alamos' Materials Physics and Applications Division, Anthony Burrell, Mark McCleskey, and Benjamin Warner, have developed a method for synthesizing pure, water-clear, ionic liquids that enable their use in a variety of applications including sensors, electrochromic devices, a medium for water detection, and a platform for biological sensors.

Electrochromic windows, which use a current to reversibly reduce and oxidize a dye that goes from a clear state to a colored state, are a natural application for these highly conductive liquids. Such windows could save the U.S. five percent in energy consumption by allowing in visible light on cold days and blocking it out on warm days. The researchers have patented several new materials based on ionic liquids for the application of electrochromic windows. ElectroChromix, Inc. has licensed the patent from Los Alamos and has made prototype mirrors. The company plans to start production next year. Electrochromic windows are currently sold as high-end rearview mirrors that automatically darken. The ionic liquid devices have significantly increased stability over the previous technology and could potentially be used as windows for buildings. (For another application of ionic liquids, see the cellulosic biomass article on page 6.)

Transparent and colored states of an ionic liquid electrochromic mirror.



Los Alamos Plasma Technology Will Make Engines Cleaner and More Fuel-Efficient

Gasoline, diesel, and turbine engines could soon burn cleaner and more efficiently through Plasma Assisted Combustion, a technology originated and developed at Los Alamos National Laboratory and now poised to enter the marketplace. The Laboratory has entered into a Cooperative Research and Development Agreement with PerriQuest Defense Research Enterprises, LLC to advance the technology for commercial refinement and implementation. PerriQuest (based in Meriden, CT), Los Alamos, and Idaho National Laboratory are collaborating on the research and development of Plasma Assisted Combustion under a licensing agreement with Los Alamos.

The technology consists of an electronic device, which can be attached to an existing fuel injector, that applies electrical voltage to the atomized fuel stream prior to combustion generating a plasma in the fuel. This effect breaks down the long chains of hydrocarbons in the fuel into smaller parts allowing the fuel to burn more completely and resulting in better mileage or reduced emissions.

"The research was really driven by market needs," said Louis Rosocha who leads the Los Alamos research team. "In 2004, regulations were announced about air pollutants by all vehicles. In the future, air pollutants by vehicles, on- and off-road, are supposed to be more highly regulated. We knew that this was going to create a great opportunity to develop a technology that would supply the demand for cleaner burning vehicles. So we decided to see if we could do something about it."

With fuel prices at all-time highs, the need for better fuel efficiency is also market driven, but the technology is limited. "The technology does produce cleaner emissions, and can lead to better fuel efficiency, but probably not at the same time," said Rosocha.

PerriQuest founder and CEO, Nicholas V. Perricone, said that his company, which routinely works with the U.S. Government on defense technologies, is dedicated to turning the plasma combustion technology into a commercial product that will improve turbine and internal combustion engines. "We knew we wanted to work with Los Alamos because not only are their scientists world-renowned, they also have some of the best plasma technologies in the world."

ENERGY RESOURCES

Publications, events, and web sites for people interested in energy-related issues

Publications

Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda

http://www.doegenomestolife.org/biofuels/b2bworkshop.shtml

Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply

http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

Fusion Energy Sciences: DOE Strategic Plan

http://www.ofes.fusion.doe.gov/News/FusionStrategicPlan.pdf

Emerging Issues for Fossil Energy and Water

http://www.netl.doe.gov/technologies/oil-gas/publications/AP/IssuesforFEandWater.pdf

Events

National Hydrogen Association's Renewables to Hydrogen Forum
October 4&5, 2006
Albuquerque, NM
http://www.hydrogenassociation.org/renewablesForum

American Nuclear Society 2006 Winter Meeting (including the 17th Topical Meeting of Fusion Energy)
November 12-16, 2006
Albuquerque, NM
http://www.ans.org/meetings/winter

The Clearwater Coal Conference: The Power of Coal
June 10-15, 2007
Sheraton Sand Key, Clearwater, Florida
http://www.coaltechnologies.com/conferences.html

Web Sites

DOE's Biomass Program http://www1.eere.energy.gov/biomass

Princeton Plasma Physics Laboratory http://www.pppl.gov
Center for plasma and fusion science managed by Princeton University, funded by DOE.

The ITER Project http://www.iter.org
An international R&D project to demonstrate the scientific and technical feasibility of fusion power.

U.S. Senate Energy & Natural Resources Committee http://energy.senate.gov/public

www.lanl.gov/energy

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