Energy

Energy research at LLNL balances the complex demands of the economy with the overall needs of the environment. The technologies we are now developing will provide both short- and long-term benefits to the nation and the world.

Clean, safe, and plentiful energy is essential to sustain a robust national economy without causing harm to the environment. The Laboratory's energy research and development efforts focus on the following areas:

- Improving the safety of nuclear power and minimizing its environmental impact.
- Developing fusion as a clean, safe form of energy for the 21st century.
- Exploring the use of alternative and renewable energy technologies while making better use of existing fossil-fuel sources.
- Working with industry to develop advanced manufacturing processes that increase efficiency and reduce waste.
- Developing transportation technologies that reduce energy use and pollution and increase efficiency and safety.

In our research, we are collaborating with other national laboratories and government agencies, large and small U.S. industries, academia, and international partners.

We have established a Nuclear Systems Safety Center as an on-line national resource for nuclear facilities across the United States. Barbara Davis, Deputy Associate Program Leader, Information Technologies, was responsible for setting up the center.

Nuclear Energy and Systems Safety

LLNL's expertise in nuclear energy spans the entire nuclear fuel cycle, including the safe operation of fission reactors, all aspects of reactor fuel materials and nuclear wastes, and systems and procedures for the safe handling and storage of nuclear materials and the security of nuclear facilities. We work closely with the DOE, the Nuclear Regulatory Commission (NRC), and other U.S. agencies to develop standards and provide objective reviews and analyses.

Nuclear Safety

In the area of nuclear safety, we develop technical acceptance criteria; conduct technical reviews; provide technical oversight for compliance for the handling, transportation, and storage of nuclear materials; and work to minimize the environmental consequences of energy production and use. For example, we are performing criticality calculations to help the DOE's two gaseous diffusion uranium enrichment plants operate safely. We have also reviewed more than eight current designs of spent-fuel storage casks for the NRC to permit continued operation of two nuclear power plants. Finally, our expertise in high-reliability software helped the NRC meet the DOE's schedule for advanced light-water reactor licensing.

With the breakup of the Soviet Union, Ukraine can no longer ship spent fuel from its operating reactors to Russia. Therefore, Ukraine is developing safety regulations for handling and storing nuclear materials within its own boundaries. We are working with the NRC to advise Ukraine in establishing a regulatory framework for transporting and storing nuclear materials. We are also supporting the DOE in the procurement of highly enriched uranium from Russia and in related issues.

Yucca Mountain Repository

We continue to work with the DOE in studies for a potential permanent repository for high-level radioactive waste at the Yucca Mountain site in southern Nevada. (U.S. law mandates a mined geological disposal system for the waste.) We are responsible for establishing the scientific bases for the design of the waste package. Central to this effort is a determination of the surrounding geologic environment that can affect the performance of the waste package. We continue to explore our "extended dry" concept—a method using the heat released from the radioactive decay of the nuclear waste to keep moisture away from the waste package for tens of thousands of years. This concept could cost less, improve performance, and garner greater public and scientific acceptance of the potential Yucca Mountain site.

We are preparing to simulate repository conditions in a large block of rock at the site to study the effects of heat, stress, hydrology, and geochemical changes.

Nuclear Facility Safety

We support the DOE in meeting security requirements at LLNL and other DOE nuclear energy-related facilities. Argus is an interconnected computer-based personnel access system that serves LLNL's Livermore and Site 300 facilities. We are developing an Argus installation for the Pantex Plant in Texas to meet the latest security requirements, and installation work is under way. Recently, the DOE selected Argus as the standard automated electronic security technology to be used by the entire DOE complex because of its reliability, adaptability, and high performance.

We are developing an upgrade to the systems used by the Office of Personnel Management and the DOE to process new security clearances and reinvestigations. This upgrade will replace the current paper-intensive process with privacy-enhanced electronic data entry and communications to shorten the clearance cycle and greatly reduce costs.

National Performance Review

In 1994, we assisted the Administration's National Performance Review (NPR) organization in understanding and using the National Information Infrastructure. The NPR's objective is to "reinvent" government to be more responsive to the public. The electronic tools we provided are helping to make NPR information available electronically and to collect public comments via the Internet.

Magnetic Fusion Energy

In the 21st century, magnetic fusion could be the source of large amounts of electricity without contributing to global warming or acid rain. The U.S. goal is to have a magnetic fusion Demonstration Power Reactor online by the year 2025. LLNL continues to collaborate in developing the next generation of tokamak fusion reactors, including both the Tokamak Physics Experiment (TPX) and the International Thermonuclear Experimental Reactor (ITER). (See pp. 22–23 for an account of our work in inertial fusion energy.)

The DIII-D

A major design concern for current tokamaks is that the exhaust of most of the power is through the plasma edge, where it is concentrated in a small area called the divertor. A primary focus of our collaboration with General Atomics in San Diego is to lead the development of a new concept for an improved divertor that will spread the heat flow. In 1994, we installed a microwave interferometer to measure electron density in the divertor region and applied theoretical codes to determine the details of the divertor structure. We have now begun final design of a radiative divertor for the DIII-D tokamak. This work will also guide the design of both TPX and ITER.

Our work with General Atomics on the DIII-D is also supporting advanced tokamak concepts, in particular, with measurements of the plasma current profile, especially at the plasma edge. We are using a new diagnostic instrument

Highlights for 1994

- Developed a concept for a practical, hydrogen-fueled, five-passenger hybrid-electric vehicle that has a gasoline equivalent mileage of more than 90 mpg and a 300-mile range.
- Received an award from the American Chemical Society for work in modeling hydrocarbon combustion in internal combustion engines.
- Tested a prototype electromechanical battery at reduced speeds, and exceeded a specific power of 8 kW/kg with a measured recovery efficiency of more than 92%.
- Received an R&D 100 award for the air-bearing LVDT amplifier we developed, which advances the state of the art in contact measurement.
- Helped Ukraine establish a regulatory framework for transport and storage of nuclear materials within that country's boundaries.
- Prepared to simulate repository conditions in a large block of rock for the Yucca Mountain nuclear-waste repository site.
- Began the major implementation phase of the Argus personnel-access security system at the Pantex facility in Texas.
- Began final design of a new radiative divertor for the DIII-D tokamak at General Atomics, based on a concept we developed.
- Installed new diagnostics on the DIII-D tokamak, including a new microwave interferometer to measure electron density in the divertor region and eight new channels of a diagnostic instrument to measure the edge-plasma current profile.
- Continued leading a national team in designing the proposed Tokamak Physics Experiment (TPX) to demonstrate continuous operation of a tokamak.

For the Yucca Mountain Project, we will use this large block of rock to simulate repository conditions and to study the effects of heat, stress, hydrology, and geochemistry.

to determine the current profile in different regimes of operation. In 1994, we installed eight new channels to measure the edge-plasma current profile.

We are also developing and implementing high-performance communications networks and distributed computing for conducting tokamak experiments from a distant site. This network would allow researchers to work at various national research facilities without having to leave their home institutions.

The TPX

The Tokamak Physics Experiment is a national initiative—now in the design stage—to demonstrate continuous tokamak operating modes with both high plasma pressure and enhanced confinement. The advanced modes are based on experimental results from present pulsed devices. The proposed TPX facility will provide data that will lead to more compact, economically attractive fusion reactors—including the Demonstration Power Reactor. The TPX is envisioned as a national facility, to be located at the Princeton Plasma Physics Laboratory. It is being designed by a team of researchers from several U.S. fusion institutions (including LLNL), with the Laboratory's Keith Thomassen serving as Program Director.

The ITER

We have been a major participant in the International Thermonuclear Experimental Reactor—a collaboration among the European Community, Japan, the Russian Federation, and the United States—since the conceptual design began in 1987. Now, during the engineering design activities, we have personnel on both the U.S. ITER Home Team and the Joint Central Team that will design the 1.5-GW facility. We are supporting both the engineering and physics design, have a primary role in the research and development of the superconducting magnets, and are performing additional work on the divertor design and on systems analysis.

FENIX

The Laboratory's Fusion Engineering International Experiment (FENIX) Facility is the premier test facility for superconductors of the size and type needed for the next generation of tokamaks, such as the TPX and ITER. We have begun testing sample superconductor materials for the ITER from the European Community and Japan. Data from such tests will allow tokamak designers to calculate the performance of system elements using various possible materials. FENIX permits the testing of large samples (5 m long) under realistic conditions, with magnetic fields up to 14 T and currents up to 45,000 A.

Numerical Tokamak

We continue to develop the theoretical understanding and computer codes needed to interpret and support magnetic fusion research. We are developing a "numerical tokamak," which is a physics-based computational model of an entire fusion device. The model is being made possible only now with the advent of more powerful supercomputers. A national consortium (of which we are a member) has progressed in developing codes to simulate the turbulent transport of energy out of the core of the plasma, a critical problem in fusion research. We have also developed and demonstrated techniques to integrate the output of such codes into a comprehensive simulation.

Hydrogen as an Alternative Fuel

Hydrogen is a potential vehicular fuel that can be produced from various domestic sources. Its use as a transportation fuel would improve the U.S. balance of payments and increase national energy security. The use of hydrogen would also have environmental benefits because it produces no hydrocarbon, CO, or CO_2 emissions when burned.

Hybrid Hydrogen-Electric Car

In 1994, we designed a conceptual hybrid-electric car that uses hydrogen as a fuel burned in an optimized internal combustion engine, gets the equivalent of more than 90 mpg, has a 300-mile range, and produces far less pollution than a gasoline-powered vehicle. We also developed a hybrid vehicle evaluation code that simulates vehicles made from various components. This code allows us to integrate the infrastructure issues necessary to support a hydrogen-fueled transportation economy, particularly in the transition from gasoline to hydrogen as a vehicle fuel. Our studies indicate that, in addition to having environmental benefits, the high efficiency of hydrogen-fueled vehicles would make their cost competitive with today's gasoline-powered cars.

Hydrogen from Municipal Waste

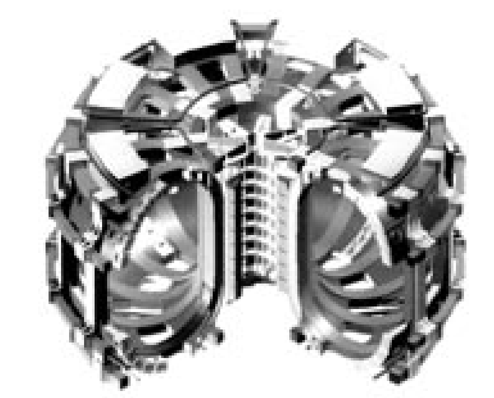
We are working with Texaco Inc. to develop a commercial system for gasifying municipal solid waste to produce hydrogen. Such a process would solve two problems: the effective disposal of significant quantities of waste and the production of an environmentally benign fuel.

Hydrogen Storage Technologies

Other work involves materials that can be used as effective storage media for hydrogen, either on board a vehicle or for transporting hydrogen between production and utilization points. We are investigating the use of carbon aerogels for on-board use to supplement high-pressure storage. We are also investigating glass microspheres, similar to laser fusion targets, as a practical and safe method to transport bulk hydrogen over long distances.

Fuel Cells

When fuel cells become more cost-effective, they are viewed as the "right technical choice" for hydrogen-powered electric vehicles (instead of internal combustion engines). In 1994, we began to apply our ultrathin-film techniques to fabricate advanced solid-oxide fuel cells that are more efficient and lighter, and that operate at lower temperatures, making their use more likely in vehicles. This project could result in methods to fabricate fuel cells that have dramatically higher power densities, specific power, and reliability and that have a strong potential for low production costs.



We are responsible for the superconducting magnet systems for the planned Tokamak Physics Experiment. This will be the first tokamak with fully superconducting magnetic field coils using advanced conductors. This computer model shows the magnets (orange) and the magnet structure and casings (blue).

Energy, Manufacturing, and Transportation Technologies

The following sections highlight our technologies in energy production, manufacturing, and transportation.

Oil Field Imaging

Much of the remaining oil in the U.S. lies within existing fields, but it is currently unavailable because of the geological complexity of the reservoirs. New technology, such as our underground imaging tools, is needed to tap this resource. Our technology uses radio-frequency electromagnetic radiation—and high-resolution imaging software developed in conjunction with industry—to monitor the movement of steam injected underground to enhance the recovery of oil. Our technology can also be used to locate bypassed oil, to monitor saltwater intrusion into aquifers as a result of oil or gas production, and to support environmental remediation. We are testing this technology at an oil field in central California and have a CRADA with an oil-field service company for further developmental work.

Combustion Research

We developed and tested a computer model for analyzing the combustion in industrial burners and applied that model to the problem of reducing the emissions of NOx, unburned hydrocarbons, and volatile organic compounds. The Clean Air Act regulates the allowed level of such emissions; the model we developed will make it possible to design economical burners that comply with those limits.

In related work, we established a consortium with Sandia National Laboratories, UCLA, and six

A prototype of our electromechanical battery, which is based on the flywheel concept of energy storage. Top to bottom: the high-speed rotor, the rotor in motion, the enclosed battery.

petroleum refiners to study emissions from refinery processes. The consortium's work will lead to a better understanding of the combustion processes and to modifications for reducing emissions.

Our work on modeling hydrocarbon combustion in internal combustion engines has received the American Chemical Society's Thomas Midgley Award. The award recognizes our "outstanding research contributions in the field of chemistry related to the automotive industries." This was the first time a national laboratory received this award.

Electromechanical Battery

We are developing modular electromechanical batteries that are based on the flywheel concept of energy storage. Small modules (1-kWh) could be used in electric or hybrid-electric vehicles, and larger modules (2- to 25-kWh) could be used for power conditioning, load shifting, and distributed energy storage. We expect these modules to have a maintenance-free lifetime of 10 years or more.

Our batteries consist of a high-speed fiber-composite rotor, supported by a magnetic bearing system, integrated with a special ironless generator/motor, and housed in a sealed, evacuated enclosure. One prototype module has been tested at reduced speeds (40,000 rpm) and exceeded a specific power of 8 kW/kg with a measured recovery efficiency of more than 92%.

Power glitches—brief interruptions or surges—are a major problem for facilities with sensitive computer chips. We recently signed a CRADA with Trinity Flywheels Batteries Inc. and Westinghouse Electric Corporation for development and testing of electromechanical batteries to be used in smoothing out the flow of electricity for factories, computer centers, and other facilities. We have also entered into a CRADA with General Motors Corporation for evaluating these electromechanical batteries as part of a system to power future automobiles.

LVDT Amplifier

We developed a high-precision, low-noise amplifier that measures displacement in high-precision machine parts. This air-bearing linear variable differential transformer (LVDT) amplifier, which received an R&D 100 award in 1994, was developed under a CRADA with Lion Precision, Inc. It can be used by machine tool builders, metrologists, and quality inspection departments. More accurate measurements will help reduce costs and minimize material waste in manufacturing.

Diesel Engine Inspection

Under a CRADA with Caterpillar Inc. we are developing technologies to monitor and inspect diesel engine components made from both traditional and nontraditional materials. The nontraditional materials—which include ceramics, metal matrix composites, and fiber composites—are used to produce diesel engines that are more efficient and less polluting, and that have a longer service life.

The inspection technologies include computed tomography (CT), digital radiography, and film-based and filmless imaging. In this work, we have optimized medium- and high-energy CT systems to inspect engine components, and we have performed radiographic and CT inspections on 12 different kinds of components. We routinely transfer this technology to Caterpillar, and a prototype system is planned for a Caterpillar production line soon.

Nondestructive Inspection

For the Federal Aviation Agency, we are developing heat-stimulated dual-band infrared (DBIR) pulsed-thermal imaging technology to quantify corrosion on aircraft. DBIR thermal imaging has potential for developing a fast, safe, noncontact tool for wide-area coverage, thus reducing both the costs and time involved in inspection. We are also studying the feasibility of using DBIR thermal imaging to inspect concrete bridge decks for hidden defects for the Federal Highway Administration. We proved that this technology can determine simulated defects 10 cm deep in an asphalt-covered concrete slab. Our next step will be to design and build a mobile DBIR imaging system to inspect bridge decks from a moving vehicle.

Partnership for New Generation Vehicles

The Laboratory is a participant in President Clinton's Partnership for A New Generation of Vehicles initiative. All projects involve collaboration with other DOE laboratories and with the Big Three U.S. automotive manufacturers. Our focus is on low-emissions catalysis, NOx sensors and systems (engine management) for diesel engines, advanced composite material modeling, and computational fluid dynamics for combustion analysis, drag reduction, and under-the-hood thermal management.

Radio-Frequency Vehicle Identification

We demonstrated the feasibility of radio-frequency technology to remotely identify vehicles fitted with electronic tags (i.e., small receivers with read/write capability). A reader sends a signal to activate the tag, which, in turn, sends encoded data back to the reader.

We are assisting the Federal Highway Administration in developing a national vehicle-to-roadway standard for identifying commercial vehicles. This technology can automatically clear trucks at highway speeds upstream from a weigh station.

In partnership with the California Department of Transportation, we developed a prototype system for automating toll collections. Without pausing, the tagged car signals roadside equipment to automatically debit an account for the toll. This system could also be used for on-vehicle probes to provide information about traffic conditions.

Refuelable Battery for Fleet Electric Vehicles

We are testing a zinc-fueled battery that can provide electric vehicles with a 300-km range, safe acceleration, and rapid refueling in 10 minutes. Because the battery is refueled with user-recycled zinc rather than recharged, it can operate nearly 24 hours a day and requires no commercial infrastructure for support. Zinc particles are gravity-fed to the cells from an internal hopper and react with air to generate liquid zinc-oxide products and electricity. A simple low-cost unit refuels the batteries by hydraulically removing the reaction product from a storage tank in the battery and returning a fresh slurry of zinc particles. The overall energy efficiency of zinc-fueled electric vehicles (with regenerative braking) is roughly comparable to conventional automobiles using gasoline. This battery could increase the feasibility of fleet electric vehicles by increasing their range and allowing nearly continuous use.

Crash Testing by Computer

Computer codes that we developed (DYNA3D and NIKE3D) have been used to analyze how vehicle structures react in a crash and to assess the crashworthiness of particular vehicle designs. In conjunction with Kaiser Aluminum and Chemical Corporation and as part of the CALSTART consortium, we are designing and analyzing a crashworthy aluminum frame that could be used for electric vehicles.

Summary

Our near-term goals include the development of innovative technologies, such as electro-mechanical batteries, that will have a major impact on the nation's transportation industry, and the development of hydrogen as a practical and economical transportation fuel. We will expand our technology base in fission energy and systems safety, applying it to both nuclear and non-nuclear projects. We will also contribute to the national magnetic fusion energy program on the DIII-D, TPX, and ITER projects, with special focus on improving the tokamak concept.

For further information contact David E. Baldwin (510) 423-1415.

We are designing and analyzing a crashworthy aluminum frame that could be used for electric vehicles. We are working as part of the CALSTART consortium and in conjunction with Kaiser Aluminum and Chemical Corporation.