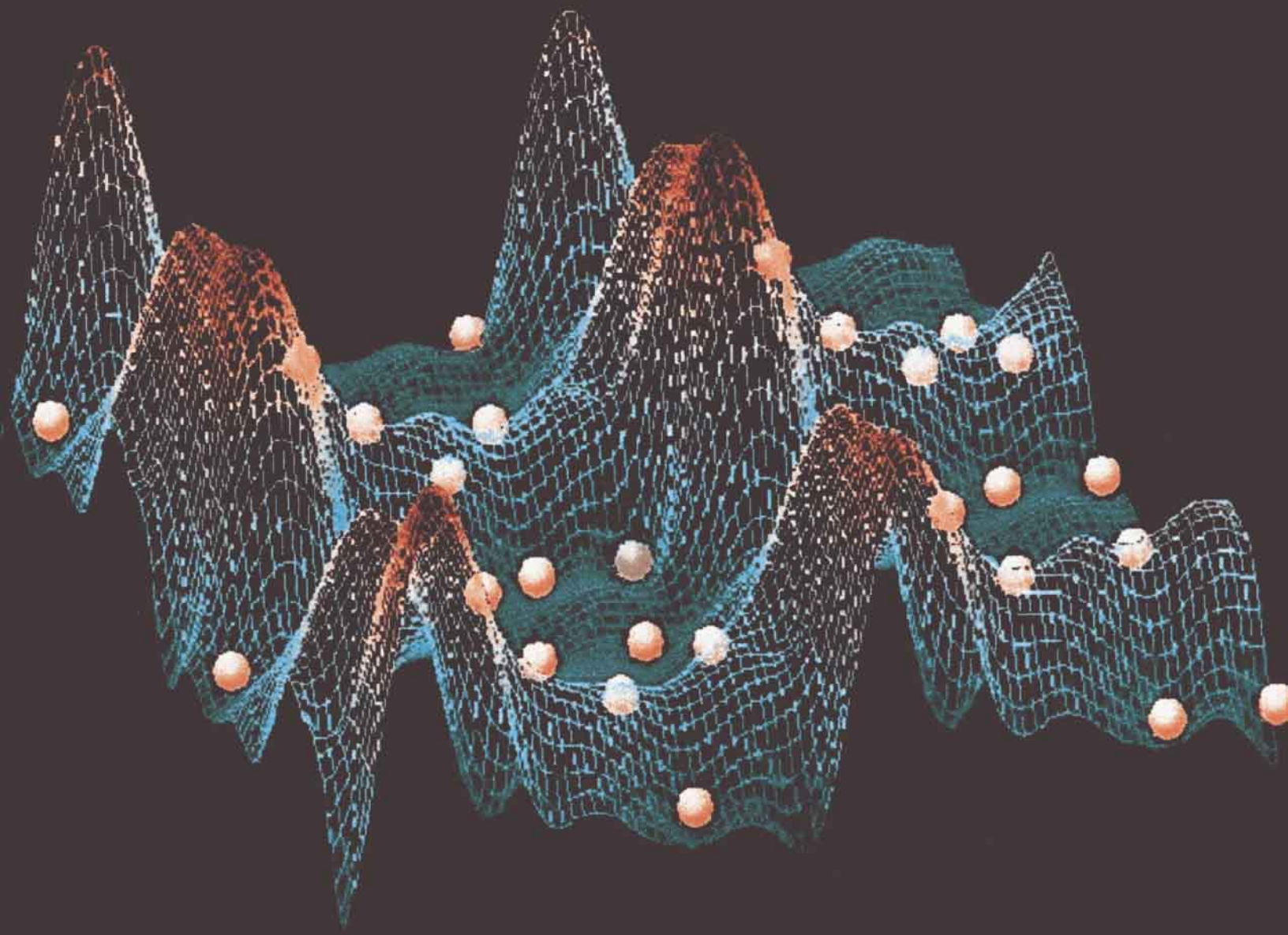
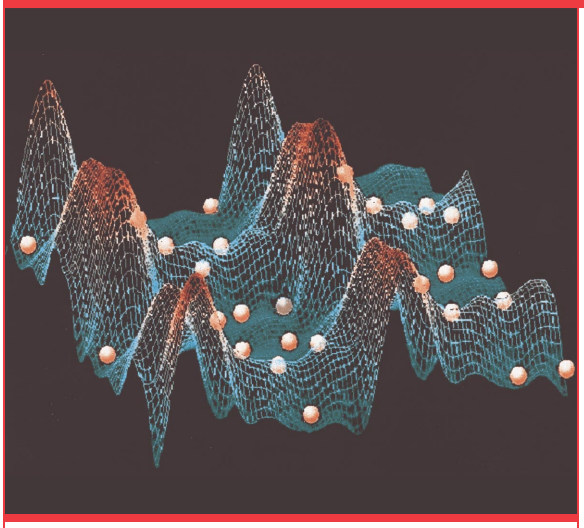
Institutional Plan 2000-2004



NREL

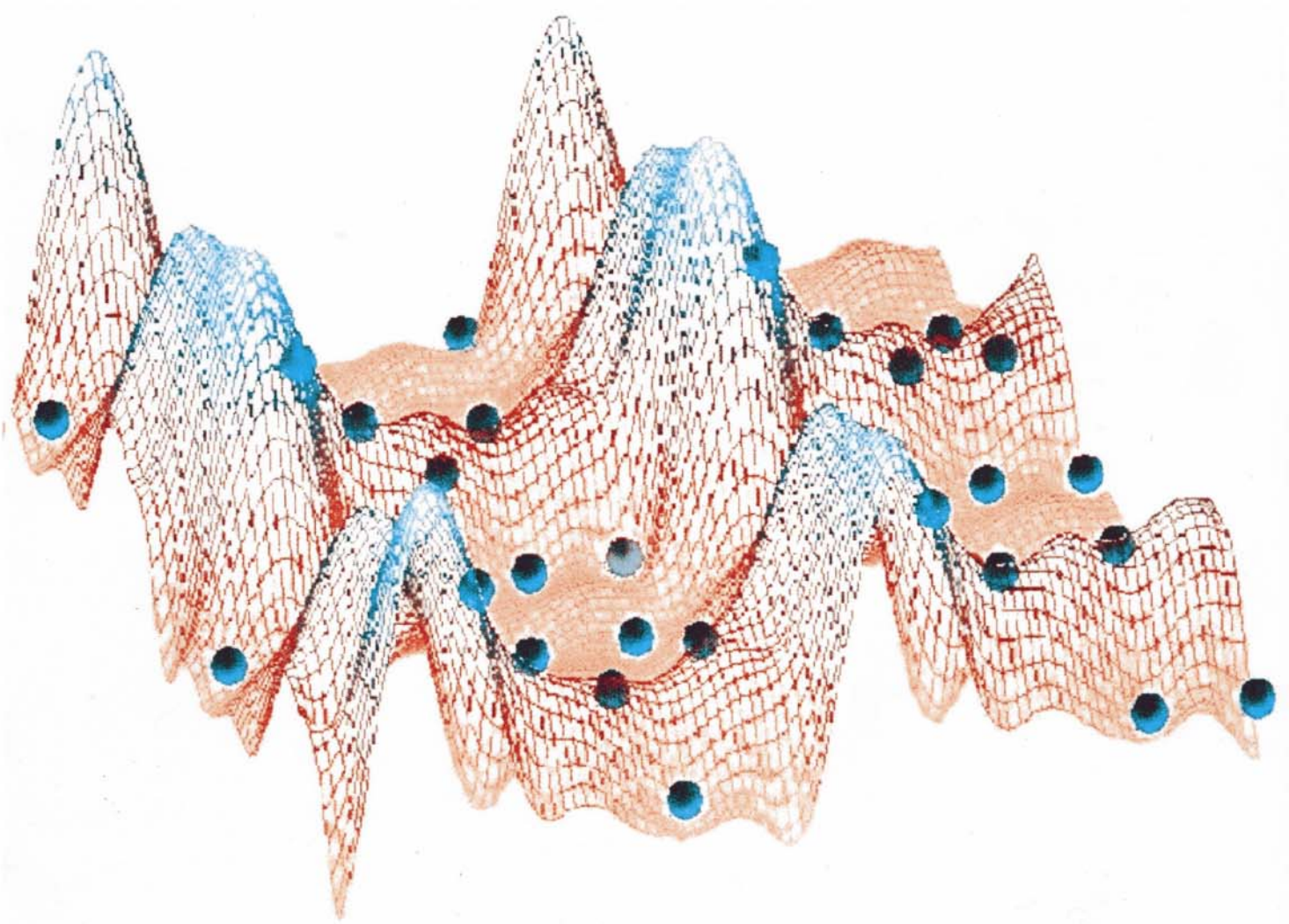
National Renewable Energy Laboratory



The front cover shows a simulation of the positron wave function localized by dangling bonds. This theoretical calculation correlates well with results obtained from a new approach – positron annihilation – for exploring defects in hydrogenated amorphous silicon (a-Si:H), one of the most promising materials for low-cost solar cells. The quantitative information derived from positron annihilation should lead to better understanding of the structure and electronic properties of a-Si:H. (This research, supported by the office of Basic Energy Sciences, was performed by scientists at NREL, Washington State University, and Brookhaven National Laboratory.)

Institutional Plan 2000-2004

May 2000



NREL

National Renewable Energy Laboratory

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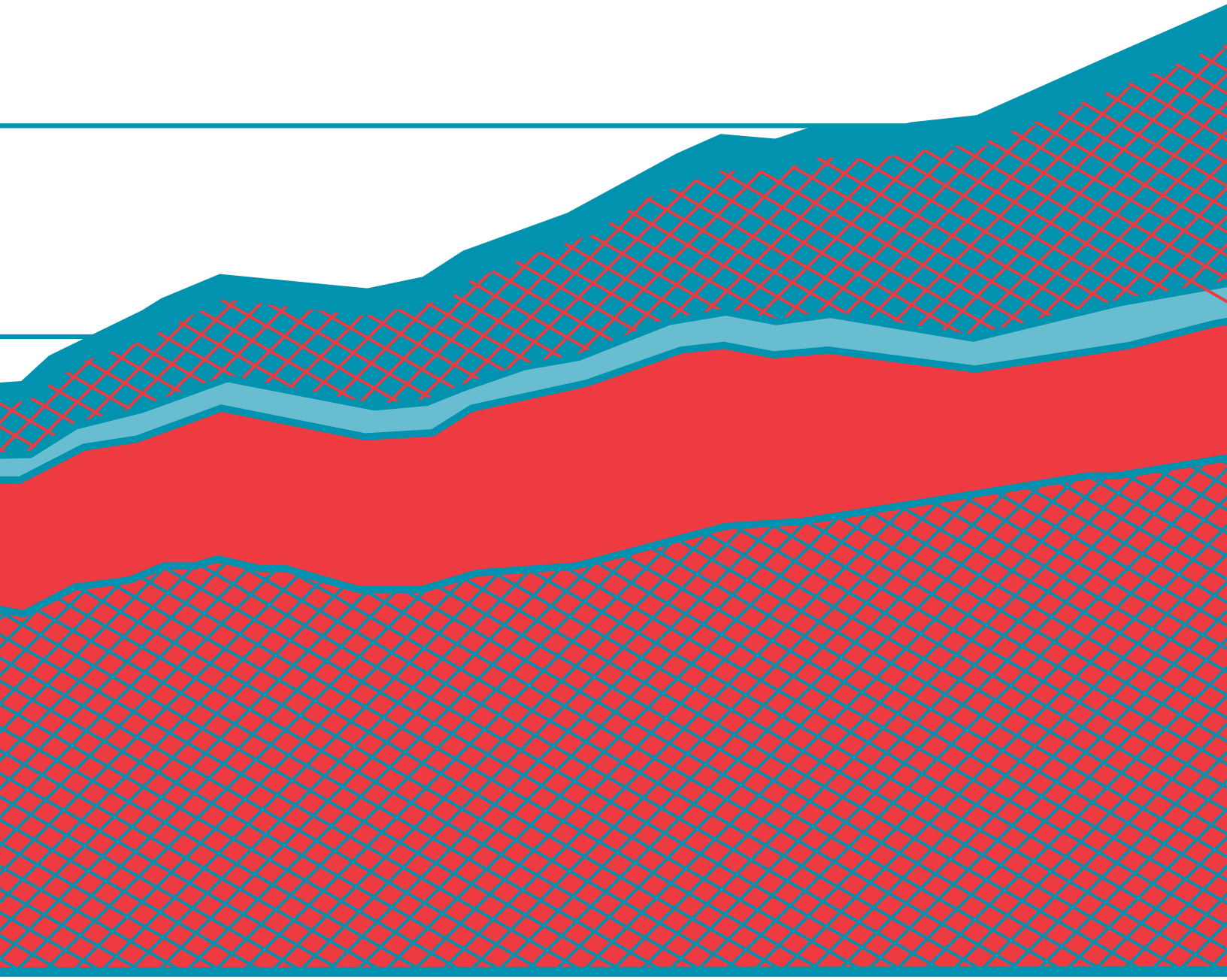
The ultrafast laser system is used in several techniques, including differential absorption measurements and time-resolved photoluminescence, to measure fundamental material and opto-electronic properties of photovoltaic and other solid-state materials.

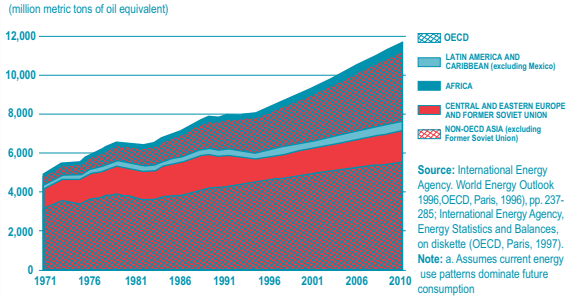
Director's Statement



1976 1981 1986 1991 1996

Global Energy Use Is Projected to Rise

Past and Projected Trends in Energy Demand, 1970-2010



Source: International Energy Agency. World Energy Outlook 1996,OECD, Paris, 1996), pp. 237-285; International Energy Agency, Energy Statistics and Balances, on diskette (OECD, Paris, 1997).
Note: a. Assumes current energy use patterns dominate future consumption

Between 1971 and 1996 global energy consumption rose nearly 70%. According to the International Energy Agency (World Energy Outlook 1996), if current patterns persist, then consumption will increase another 30% by 2010. To meet rising energy needs, while ameliorating damage to the environment, renewable energy and energy efficiency technologies must become significant players in the global energy infrastructure.

At the dawn of the 21st century, the United States faces major energy-related challenges. Uninterrupted energy supplies are crucial to national security, economic well being and continued U.S. leadership in highly competitive world markets. Yet America now depends on other nations for more than half its oil, at a cost of almost $60 billion every year. And, the environmental challenges of a fossil-fuel-based energy economy continue to capture headlines in this country and around the world.

These challenges are made more acute by what is happening overseas today. Population growth and economic development in Asia, Africa, and Latin America have combined to lead a rapid expansion of global energy demand. Today's developing nations, with nearly 80% of the world's population, account for only a third of all energy use. But their electricity growth rate is seven times that of industrialized nations. If these growth trends continue, developing nations will become the world's primary energy consumers within two or three decades. Total world energy use is expected to double by the year 2025 and quadruple by 2100. This will likely pose significant challenges as nations struggle first to finance the expensive infrastructure required to transport and use fossil fuels and then to gain access to dwindling supplies of these fuels. This demand for new energy will also put enormous pressures on the environment around the world.

Economic development and political stability will be key factors in developing markets. Energy security and environmental impact will be important drivers at home and abroad. We know that energy sources and energy use will be different in the new century; many diverse solutions will be required in terms of fuels, technologies, ownership, and distribution infrastructure. Energy efficiency and renewable energy can help reduce political tensions caused by resource conflicts, address environmental problems, and contribute to economic development, especially when viewed as integral parts of a diverse energy portfolio.

This diversity will be driven by local and global limits on energy resources, competition in free markets, availability of new technology choices and the opportunity to apply new supply and distribution options in places without existing infrastructure. Almost all scenario planners — from multinational oil companies to the World Bank — agree that this increased energy supply diversity around the globe will include progressively increasing use of renewable energy throughout the next century. It is not a question of *if*, but one of *how much* and *how soon*. And the answer to that question has everything to do with how we invest in the future — both in technology and in policy actions that reduce market barriers.

Great strides are being made in developing new energy technologies, in ways to use less energy to achieve greater productivity, and in strategies

to move these developments from concept to reality. As exciting as the future can be with these advances, history tells us it takes time to change the energy mix.

The entire path on the way to the changing energy mix is important because unused technology is useless technology. Without a commitment to continued research and development of energy from the sun, wind, and plant life, and of energy from the earth's own geothermal reservoirs, the potential of clean, never-ending supplies of energy will not be realized. And without a commitment to bring those technologies to market, their benefits to the environment, the economy, and energy security will be unrealized.

Pursuing this technology development and deployment is the mission of the National Renewable Energy Laboratory (NREL). As the nation's premier institution for renewable energy and energy efficiency, NREL supports the U.S. Department of Energy (DOE) by working in partnership with other laboratories, universities, and U.S. industry to help our nation provide for the energy needs of the future.

In this new century, NREL will continue to seek the most efficient and cost-effective energy technologies and assist DOE and U.S. industry in their development. We will continue to facilitate the deployment of the technologies, across all potential markets and applications — local, state, national, and international. Our core technology development in photovoltaics, wind energy, and bioenergy will continue. We will also support DOE in hydrogen, concentrating solar power, solar heat and building energy, geothermal, fuels utilization, related industrial technologies, and hybrid vehicle technology development. And we will continue our involvement in the Federal Energy Management Program, and in the cross-cutting support we provide in analysis and technical information.

Several major initiatives have been announced recently by the President (bioenergy and bio-products, nanotechnology, 21st century science fund, information technology for the 21st century), as well as by the Energy Secretary (Wind Powering America and others). We expect to increase our involvement in these important initiatives in the years to come.

We are responding to new opportunities and needs with initiatives in several key areas. One of these key areas is bioenergy, taking advantage of the explosion in the life sciences to improve and integrate the production of food, fuel, products, materials, and energy from bio-based materials such as agricultural residues and energy crops. Another key initiative for NREL will be distributed and hybrid generation, responding to the trends in the energy supply sector, focusing on the technical, system, and infrastructure barriers to distributed power and the opportunities to develop and deploy renewables in hybrid energy generating systems of all types. NREL will also pursue unique ideas to address the problems associated with high levels of atmospheric carbon by mitigating carbon dioxide emissions, building upon our expertise in electrochemistry, artificial photosynthesis, and other disciplines. Lastly, basic research is the underpinning of all our endeavors as a laboratory, and we intend to put a greater emphasis on strengthening the basic foundation of all our energy technologies to achieve greater technical performance in the 21st century.

As NREL's director, I look forward to the new century, knowing it will be a period of great change, driven by new ways of producing and using energy, both in this country and around the world. I am confident that NREL will be a vital force in that change, for the benefit of all humankind.

Richard H. Truly
Director

Laboratory Overview

This is part of the process development unit (PDU) of NREL's Alternative Fuels Users Facility. Researchers from NREL and industry use this facility and the PDU to move advances in ethanol and other biomass research into the development phase.

Mission

The National Renewable Energy Laboratory is a leader in the U.S. Department of Energy effort to secure a sustainable energy future for the nation. NREL is the nation's lead laboratory for renewable energy technologies and a primary laboratory for energy efficiency technologies. Since its opening in 1977, NREL's mission has focused on developing, advancing, and helping to deploy renewable energy and energy efficiency technologies.

NREL is a federally funded research and development center. As such, NREL is a strategic advisor and partner with DOE and assists DOE with the full range of activities from research and development through technology demonstration to facilitating deployment of these technologies into global markets. NREL is responsible for integrating the expertise and outlook of industry, academia and DOE, and collaborates fully with many different organizations in accomplishing its mission. NREL optimizes the use of in-house research and development (R&D), external capabilities, and partnering mechanisms to leverage available resources and assure the best value for DOE and the American taxpayer.

As a DOE national laboratory, NREL's mission and activities are intimately linked to those of DOE. Historically, in fact, more than 95% of NREL's funded activities have been in support of two DOE offices — the Office of Energy Efficiency and Renewable Energy (EERE) and of the Office of Science (SC). This trend continued in FY 1999 (Figure 1).

Office of Energy Efficiency and Renewable Energy. NREL conducts the great majority of its work for EERE, supporting EERE's mission to develop and deploy advanced energy efficiency and renewable energy technologies. More specifically, NREL carries out more than a dozen DOE programs (Figure 2) employing its core capabilities to advance EERE's two stated energy-related strategic goals: 1) to increase the supply & use of clean energy resources and the reliability of the energy system; 2) to increase the efficiency of the energy system. The programs and activities that NREL manages and conducts on EERE's behalf include:

- Photovoltaics — investigate and develop advanced solid-state materials, technologies, and systems for turning sunlight into electricity
- Wind Energy — develop and test advanced technologies for converting wind energy into electricity
- Biopower — develop and expand use of materials and technologies for combusting biomass to generate electricity and process heat
- Concentrating Solar Power — develop systems and materials for producing power from concentrated sunlight
- Solar Buildings — advance the development and deployment of thermal and electric solar technologies for use in buildings
- Hydrogen — research and validate technologies to enable renewable hydrogen to make the transition to a major energy carrier for electricity, heat, and transportation
- Geothermal Energy — develop advanced heat-transfer technologies for improving the performance of goethermal power plants.

NREL Mission

To lead the nation toward a sustainable energy future by developing renewable energy technologies, improving energy efficiency, advancing related science and engineering, and facilitating deployment

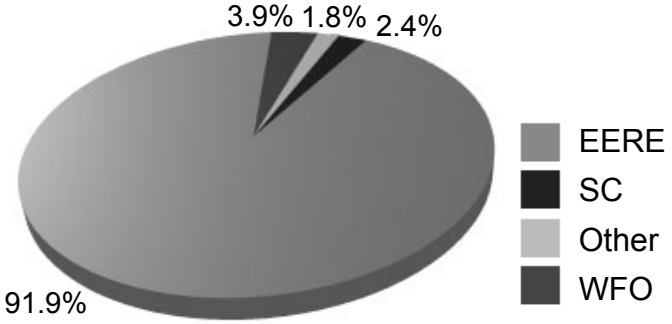


Figure 1. Keeping relatively consistent with historical trends, in FY 1999 about 95% of NREL's work was performed in support of DOE's Office of Energy Efficiency and Renewable Energy and the Office of Science — most of which was performed for EERE.

- Distributed Power — develop, promote, and advance standards, codes, and technologies for integrating modular, distributed electrical generating systems into electrical grids
- Superconductivity — research superconducting materials, wires, and tapes for use in highly efficient electrical transmission and storage
- Biofuels — develop cost-effective and environmentally friendly technologies for producing alternative transportation fuels and fuel additives
- Fuels Utilization — develop and evaluate advanced fuels for use in internal combustion engines and fuel cells
- Advanced Automotive Technologies — develop, model, and analyze systems for hybrid electric vehicles
- Buildings Technologies — develop, promote, and integrate energy technologies and practices to make buildings more efficient
- Industrial Technologies — develop advanced energy efficiency, renewable energy, and pollution prevention technology for use in U.S. industry
- Federal Energy Management Program (FEMP) — provide technical assistance to help federal facilities save energy and money through the use of energy efficiency and renewable energy technologies

In support of these and other programs and activities NREL also measures, assesses, and models renewable resources such as sunshine, wind, and biomass; performs energy, market, program, and policy analyses; and prepares and publishes information for both technical and non-technical audiences.

The Office of Science is DOE's primary sponsor of basic research, providing the scientific foundations for DOE's applied missions. In support of the DOE mission and goals, the

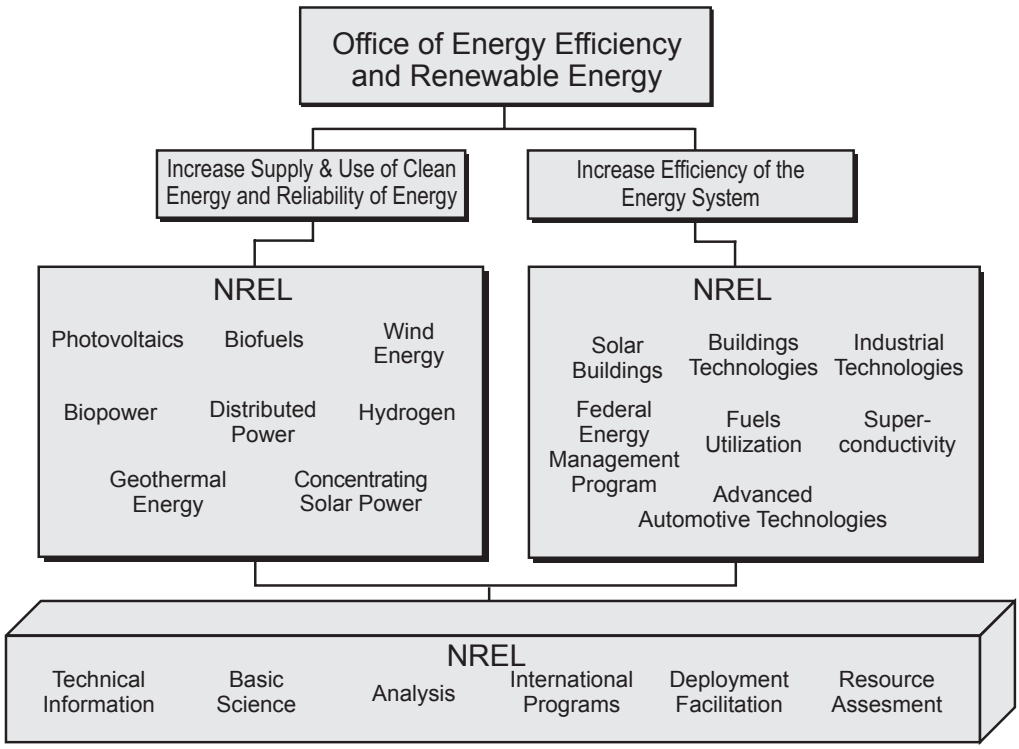


Figure 2. The majority of NREL's capabilities and programs are geared to support the two primary goals of DOE's Office of Energy Efficiency and Renewable Energy.

Office of Science collaborated with 100 of the nation's top scientific professionals to craft four scientific themes (Fuel the Future, Protect Our Living Planet, Explore Matter and Energy, and Provide Extraordinary Tools for Extraordinary Science) on which to build the scientific foundations for a strong and prosperous nation in the 21st century. Through its capabilities in fundamental materials sciences, chemical sciences, and biological sciences, NREL supports all four of these themes, but especially that of Fuel the Future, Science for Clean and Affordable Energy (Figure 3). In addition, NREL integrates the results of the basic research it performs under the purview of SC with the more applied objectives of EERE.

Proliferation Prevention Program. NREL also supports the DOE in preventing the proliferation of weapons of mass destruction through DOE's Initiative for Proliferation Prevention Program. This program focuses on employing scientists in the former Soviet Union's newly independent states for valuable non-weapons technology development. NREL's renewable energy and energy efficiency technologies provide very attractive opportunities for these scientists; and after three years of involvement, several projects are nearing commercialization.

Work for Others. With the proviso that the work it performs does not conflict with its mission, NREL also does work with, and for, a wide range of parties outside of regular DOE program funding areas, including:

- Industry, universities, state, and local governments, and foreign entities
- U.S. federal government agencies, branches, and divisions not under the U.S. DOE
- Other laboratories and facilities within the DOE complex

The work that NREL performs for others generally takes the form of cooperative research and development agreements (CRADAs), where NREL shares resources with partners or is reimbursed for costs incurred; work-for-others (WFO) agreements, in which NREL does work for a sponsor and is reimbursed by that sponsor; or analytical service agreements, in which NREL performs testing and characterization services.

In FY 1999, NREL's work for others reached $7.4 million, an historical high.

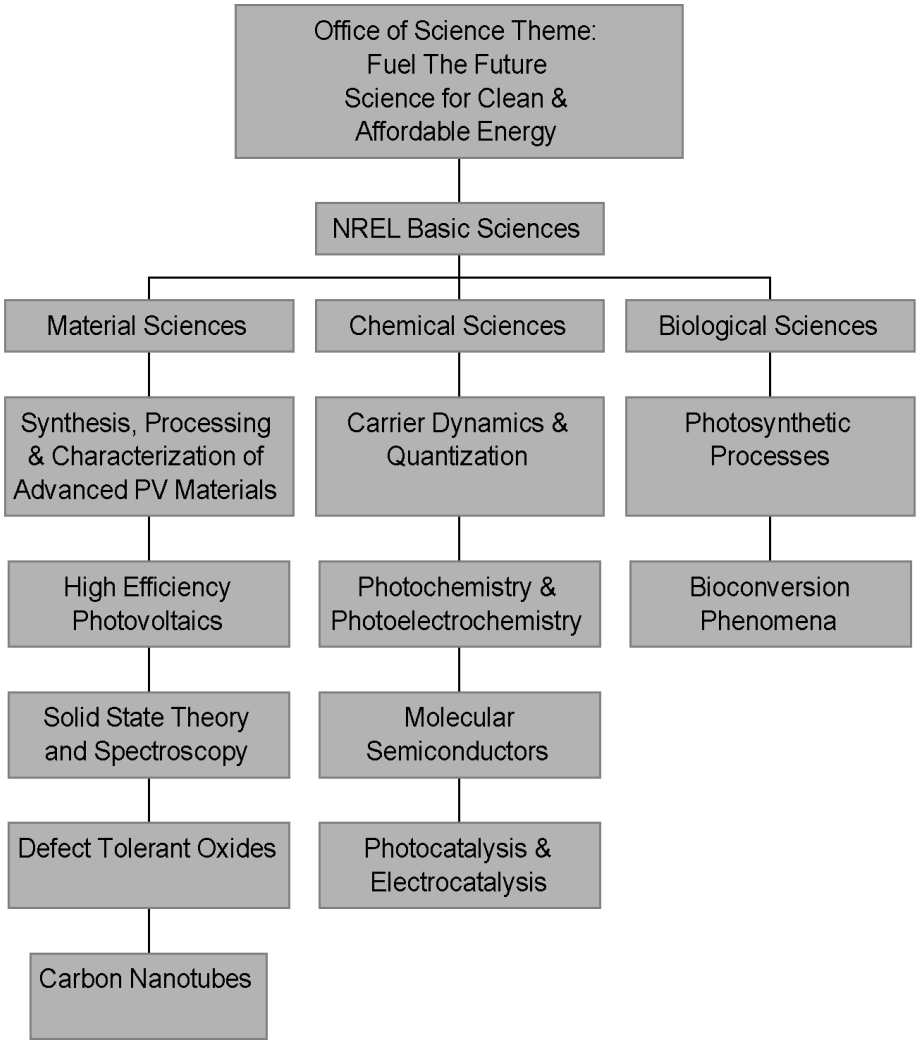


Figure 3. NREL performs research in the materials, chemicals, and biological sciences in support of the Office of Science theme: Fuel the Future, Science for Clean and Affordable Energy.

NREL Vision

NREL will be the world's preeminent institution for advancing innovative renewable energy and energy efficiency technologies from concept to adoption. By partnering with our stakeholders, we will support a sustainable energy future for the nation and the world. In achieving this next level of excellence, NREL will set the standard for others.

Vision

This Institutional Plan addresses the first five years of the new millennium (FY 2000 — FY 2004). NREL's vision for the future is a world in which:

- Access to energy resources and their consumption do not degrade the environment or depend on political stability of oil producing nations
- All people can take advantage of their indigenous energy resources
- Resources are managed as integrated systems
- Energy sources are renewed or replenished rather than exhausted
- All people will have the energy required to support economic development to enable adequate access to food supplies, medical services, education, and the general lifestyle enjoyed today by only a small portion of the world's population

Renewable energy and energy efficiency technologies hold a key to meeting the multiple challenges of achieving this vision for such a sustainable energy future. We are not alone in this view. Increasing numbers of major U.S. and multinational companies are making major investments in sustainable technology development, for their own immediate economic benefit and because they are anticipating the needs of the future. And, increasing numbers of U.S. consumers are making their desires known, not only through surveys, but also by making their own economic choice to support "green energy" opportunities through utilities. There is an excellent opportunity emerging for advancing renewable energy and energy efficiency, both within the United States and internationally. World population continues to grow at high rates, putting enormous pressures on resources and on both the local and global environment. Serving growing populations and supporting sustainable economic development for developing countries requires energy, creating projections of energy demand that escalate dramatically for the next 30-50 years.

Within the United States, stable, clean energy supplies are essential to the security and prosperity of the nation. At present, American utilities rely on low-cost fossil fuels to provide most of the energy for industry and buildings, and petroleum continues to be the primary resource for transportation. At the same time, as the environmental impacts of fossil-fuel extraction, conversion, and use become greater concerns, the nation is faced with the fundamental challenge of how to ensure a sustainable energy future. With petroleum imports now surpassing the 50% mark — more than was imported during the oil crises of the 1970's — the nation is at ever-greater risk for disruption of vital fuel supplies for transportation.

Progress toward NREL's vision will reduce the risk of energy supply disruption. The march toward a sustainable energy future will be engendered by the use of natural gas, which is currently inexpensive, relatively plentiful, and relatively nonpolluting (compared with other fossil fuels) and will serve as a bridge fuel as energy efficiency and renewable energy technologies continue to advance. In the interim, the continued growth of energy efficiency technologies in homes, commercial buildings, industry, and government will help slow the growing demand for energy, both here at home and internationally. Also, renewable energy technologies will continue to penetrate the energy infrastructure, through specialty markets, through new and emerging markets, and through major markets, where they will be integrated with the more conventional technologies and will become a pillar of the energy-supply infrastructure. Together, energy efficiency and renewable energy technologies will relieve environmental pressures, reduce our trade imbalance, increase the nation's share of the growing global energy technology markets, and make our energy supplies more secure.

Core Competencies

The ability of NREL to advance its strategic goals and to achieve its long-range vision depends upon its core competencies — the Laboratory's central capabilities, strengths, and qualities. By continuously building and augmenting these central strengths, NREL is also able to respond to the changing needs of the DOE, the American public, and of the nation and to proceed in new research directions when required. In an effort undertaken in 1994, NREL articulated its core competencies as:

- **Development and characterization of renewable energy technologies, energy efficiency, and waste conversion processes and technologies.** NREL is the nation's preeminent laboratory in renewable energy and many areas of energy efficiency technologies. Our expertise covers fundamental and applied science in the areas of photovoltaics, wind energy, biofuels, building energy, biopower, concentrating solar power, hydrogen, advanced automotive technology, superconductivity, industrial technologies, resource assessment, distributed power, and more. We employ these skills to harness complex processes that convert renewable resources into useful forms of energy and materials, and to develop technologies that save energy and make processes more efficient.
- **Integration of efficiency and renewable technologies with conventional fuel supply sources.** NREL strives to diversify the nation's energy supply options. An important way of doing this is to build the appropriate options and markets by integrating renewable and energy efficiency technologies with conventional energy technologies. This is being done in several ways using NREL expertise in alternative fuels, which can augment conventional transportation fuels; in electric generation technologies, such as photovoltaics, wind energy, and hydrogen, which can be used in distributed systems to offset demand on conventional systems, or which can be used in hybrid systems with conventional technologies, especially those using natural gas; in advanced automotive technologies such as hybrid electric vehicles, which depend upon gasoline and electricity for power; and in building technologies where passive solar, electrochromics, photovoltaics, fuel cells, and high-efficiency heat pumps can be combined with conventional systems to heat and cool buildings.
- **Systems and process engineering and integration for renewable energy and energy efficiency technologies.** Using engineering disciplines that span the range from structural dynamics, electrical and electronic engineering, chemical processing, heat and mass transfer, aerodynamics, and more, we design, build, test, and evaluate renewable energy, energy efficiency, and conversion systems in real-world environments.
- **Fundamental science related to renewable energy and energy efficiency technologies.** By studying the fundamental interaction of light with matter, we push the frontiers of knowledge in basic energy sciences to overcome technological barriers and expand the nation's energy horizons. Our expertise includes condensed matter physics, quantum theory, solid-state spectroscopy, photoelectrochemistry, computer modeling of complex systems, photosynthesis, catalysis and photocatalysis, crystal growth, electrochromics, quantum dot and nanostructured materials, bioconversion, genetic engineering, and high-temperature superconductivity.

In FY 2000, NREL intends to revisit these competencies in light of changes in programs and responsibilities. This evaluation of competencies will establish a basis for making future investments to enhance capabilities.

In addition to reviewing all competencies, NREL intends to work closely with EERE to explore the Laboratory's analytical capabilities

in more detail. Through this effort, we will develop a shared vision for the analysis capabilities and an action plan for enhancing these capabilities to meet current and future EERE needs. NREL recognizes that DOE and the Laboratory have increasing needs for high-quality energy analyses to deepen understanding of the three elements that are critical to carrying out the EERE mission — technologies, policies, and markets. To enhance capabilities to analyze these elements and their interactions, NREL will develop a collaborative Clean Energy Analysis capability that builds upon our current analysis team, makes use of an internet platform to significantly enhance effectiveness, and draws upon recognized external analytic capabilities to provide an integrated state-of-the-art analysis program to DOE and the Laboratory. This capability is further described in the Science & Technology section.

Partnerships and Collaborations

In addition, NREL has strengths in managing complete programs, such as developing partnerships for market and technology development and deployment facililation for renewable energy and energy efficiency technologies. NREL increases the public awareness of renewable energy and energy efficiency technologies and facilitates their deployment by establishing a market-driven approach to technology development; through education programs for students, teachers, the general public, and a wide variety of stakeholders; through patents and licenses; and by forming partnerships with industry, academia, end-users, other national labs, international organizations, and others.

NREL also integrates the expertise of industry, academia, and the DOE to solve complex technical problems that cannot be solved by one group alone. The energy infrastructure is vast and intricate, and the energy sciences are often difficult and complex. NREL applies its expertise in the sciences, technologies, partnering, project management, and facilitation to work with hundreds of companies and academic institutions, with laboratories of the DOE and other federal departments and agencies, and with the DOE programs to attack the technical, infrastructural, and manufacturing issues to overcome barriers to technology development, implementation, and deployment. The following Science & Technology section describes the key thrusts of each program area, and discusses the types of partnerships and collaborations that are important to each specific program.

Science & Technology

X-ray photoelectron spectroscopy (XPS) is used to perform elemental and chemical state analysis on thin films, polymers, catalysts, metals, insulators, and semiconductors.

The National Renewable Energy Laboratory manages programs and projects and performs research and development primarily in support of the goals and objectives of two DOE organizations: the Office of Energy Efficiency and Renewable Energy and the Office of Science. The Office of Energy Efficiency and Renewable Energy has organized its technology programs around the four energy use sectors of society: power (Office of Power Technologies), transportation (Office of Transportation Technologies), buildings (Office of Building Technology, State and Community Programs), and industry (Office of Industrial Technologies). NREL performs R&D and manages programs and projects that support each of these EERE offices. NREL also manages programs and projects for EERE's Federal Energy Management Program (FEMP) and EERE's Office of Planning and Budget Management (OPBM).

For the Office of Science, NREL primarily supports the Office of Basic Energy Sciences (BES) by performing research in the materials, chemical, and biological sciences that pertain to the exploitation of solar and other renewable energy sources.

Office of Energy Efficiency and Renewable Energy

Office of Power Technologies

The mission of EERE's Office of Power Technologies (OPT) is to lead the national effort to support and develop clean, competitive, reliable, power technologies for the 21st century by

- Encouraging electricity suppliers to choose and deploy renewable energy and energy efficiency technologies on an equitable basis with other supply technologies
- Addressing the technological and institutional constraints that impede the adoption of renewable energy and energy efficiency technologies worldwide
- Working with utility, industry, and other stakeholders to realize the full market potential for renewable energy and energy efficiency technologies, both in the United States and in other countries

The key strategy for achieving this mission is to establish and maintain a renewable energy technology base through an aggressive R&D program in photovoltaic, wind energy, biopower, concentrating solar power, solar buildings, hydrogen, geothermal energy, distributed power, and superconductivity technologies and systems. NREL supports this strategy by performing R&D and by leading projects and programs in each of these technologies.

Photovoltaics

NREL pursues the goals of the DOE Photovoltaics Program through the National Center for Photovoltaics (NCPV), which coordinates PV activities of both NREL and Sandia National Laboratories. The NCPV pursues several highly promising PV technologies including crystalline silicon, amorphous silicon, thin-film composites such as cadmium telluride and copper indium diselenide, and high-efficiency composites such as gallium arsenide and its alloys and multijunction devices based on them.

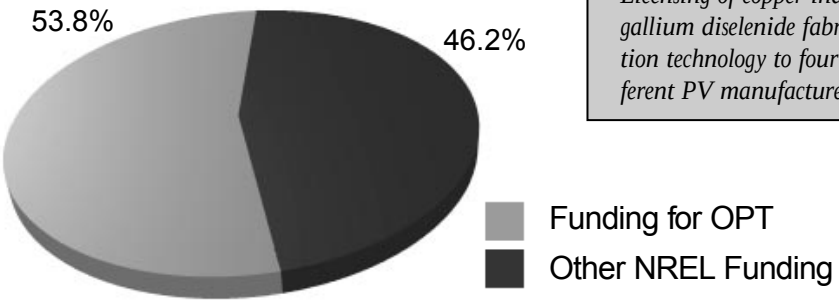


Figure 4. EERE's Office of Power Technologies funded 53.8% of NREL's activities in FY 1999, which included work in photovoltaics, wind energy, biopower, concentrating solar power, solar buildings, hydrogen, geothermal energy, distributed power, and superconductivity.

Accomplishments in PV

- *Record efficiencies for thin-film solar cells (18.8% copper indium gallium diselenide) and multijunction solar cells (32.3% gallium indium phosphide/gallium arsenide/germanium three-junction device, in conjunction with licensee)*
- *Record efficiency for a cadmium telluride solar cell (15.8%) including a greatly improved transparent conducting oxide top layer*
- *R&D 100 awards for technology developments in partnership with United Solar Systems, Inc. in 1998 (triple-junction amorphous silicon modules in PV shingles) and with Siemens Solar, Inc. and the California Energy Commission in 1999 (first commercial copper indium diselenide modules)*
- *Licensing of gallium indium phosphide/gallium arsenide tandem solar cell technology to the two largest suppliers of power systems for satellites — TECSTAR (supplier to Lockheed-Martin Missiles and Space) and Spectrolab (supplier to Hughes Aircraft)*
- *Licensing of copper indium gallium diselenide fabrication technology to four different PV manufacturers.*

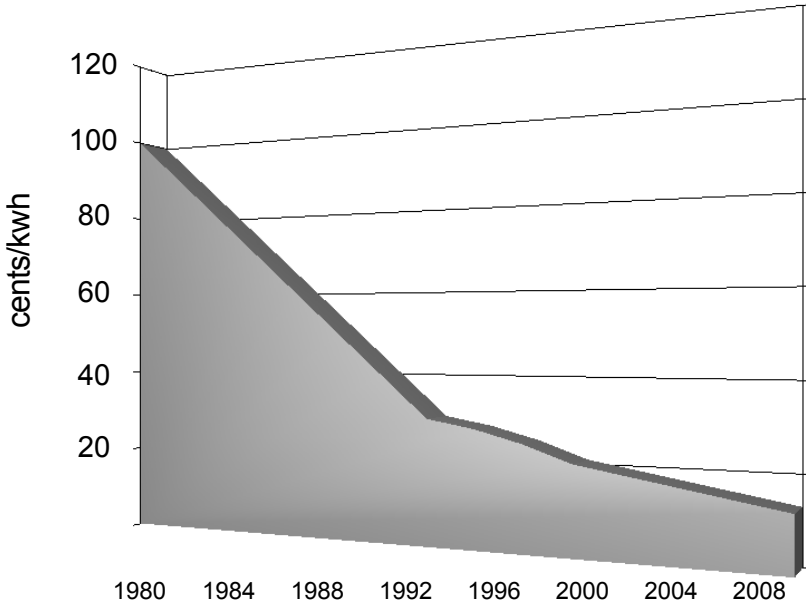


Figure 5. The cost of photovoltaic electricity has dropped from more than $1/kWh in 1980 to nearly 20¢/kWh today. With continued technological advances and with economies of scale, the cost will keep dropping.

Photovoltaic devices take advantage of the fact that the energy in light will free electrical charge carriers in certain materials when it strikes those materials, making it possible to capture that light energy as electrical current. Solar cells and modules using this photovoltaic effect are ideal energy generators in that they require no fuel, generate no emissions, have no moving parts, can be made in any size or shape, and rely on a virtually limitless energy source.

Figure 6. At Dangling Rope Marina on the isolated north shore of Lake Powell in southern Utah, a 115-kW photovoltaic system supplies electricity for the marina, displacing the need for 65,000 gallons of diesel fuel per year.

In the last four decades, solar cells have become a standard technology for uses such as satellites, rural electrification, water pumping, communication equipment, road signs, and other situations where electrical grid connection is difficult or expensive. The U.S. PV industry shipped 61 megawatts of solar cells and modules in 1999 with sales growing more than 20% per year on average. The basic goal of the DOE/NREL PV Program is to reduce the cost of PV technology so that it becomes economically competitive for additional uses, including main grid electrical generation.

Direct research and development is just one part of NREL activities in support of DOE PV Program goals. More than half of the program budget is for subcontracts to university and industry partners. Two major FY 1998 solicitations to universities and one to thin-film PV industries set up extensive ongoing research and development work. Important subcontracts supporting technology development were also initiated by FY 1998 solicitations. Systems engineering and applications work centers around making systems that meet the performance, reliability, and lifetime demands of users; that meet mechanical, electrical, and safety code standards; and that may easily be integrated into a wide range of applications.

Two new initiatives are being started in FY 2000. *High-performance PV* would push existing technologies toward their ultimate performance limits, doubling efficiencies to achieve one-third energy capture by 2010. *PV beyond the horizon* would nurture research into nonconventional breakthrough technologies to set the stage for large-scale competition with other energy technologies.

Major program thrusts during the next five years include university research on future generation PV technologies, developing high-performance thin-film and concentrator PV technologies, improving manufacturing processes and expand-

ing the production capacities for PV modules, improving the reliability of modules and systems, and facilitating the markets for PV to support industry's goal of 25% annual growth rate.

During the next five years, NREL expects to:

- Initiate projects targeting a doubling of PV performance from 1999 commercial levels
- Expand fundamental R&D for conventional and nonconventional PV technologies
- Identify and focus on new projects on intelligent processing, in-situ diagnostics, and related areas to meet industry needs
- Start construction of NCPV Science and Technology Facility (which will be used to support new initiatives and help industry move rapidly from laboratory-scale demonstration of new technologies to first-time commercial manufacturing and intelligent manufacturing)
- Demonstrate a stable 13%-efficient a-Si cell and a 20%-efficient polycrystalline thin-film cell
- Demonstrate potentially low-cost, high-quality, thin-layer silicon growth on a foreign substrate
- Demonstrate the feasibility of a 3-junction device for 38%-efficient solar cell under concentration
- Support the successful transition of CdTe and CIS to multi-megawatt production
- Demonstrate a monolithic, series-connected, multijunction polycrystalline thin-film device
- Refine and transfer a manufacturing-friendly electro-optical-based diagnostic technique to the PV industry
- Demonstrate the achievement of voltage addition in a 4-junction device
- Demonstrate a 10%-efficient commercial CdTe module
- Complete capability to evaluate multijunction concentrator cells and modules to 1000X with ±3% uncertainty
- Implement new partnerships to address processes capable of $1/watt direct module manufacturing costs with gigawatt production capacity

Wind Energy

The mission of the U.S. Department of Energy Wind Energy Program is to enable U.S. industry to complete the research, testing and field verification needed to fully develop advanced wind energy technologies that lead the world in cost-effectiveness and reliability. NREL pursues the goals of the Wind Energy Program through the National Wind Technology Center (NWTC), a 280-acre campus 18 miles north of the main NREL campus. The NWTC has 16 outdoor turbine test pads, laboratories for testing strength and performance of turbine components, a new Industrial User Facility, and a 2-MW dynamometer for commercial manufacturers to test their own components with the assistance of NREL engineers.

Modern wind turbines use blades attached to a central shaft to capture wind energy and rotate the shaft, much like old-fashioned windmills, but turning electrical generators instead of providing mechanical power. By designing blades specifical-

Accomplishments in Wind Energy

- *Comparison of wind turbine design codes verified that U.S. codes handle advanced flexible turbines more accurately than European codes and validates their use for certification analysis as well as design*
- *Joint operating program established with Underwriters Laboratories as a U.S. certification agent, facilitating sale of U.S. manufactured turbines in Europe*
- *Valuable technical support provided to three major advances by individual U.S. turbine manufacturers*

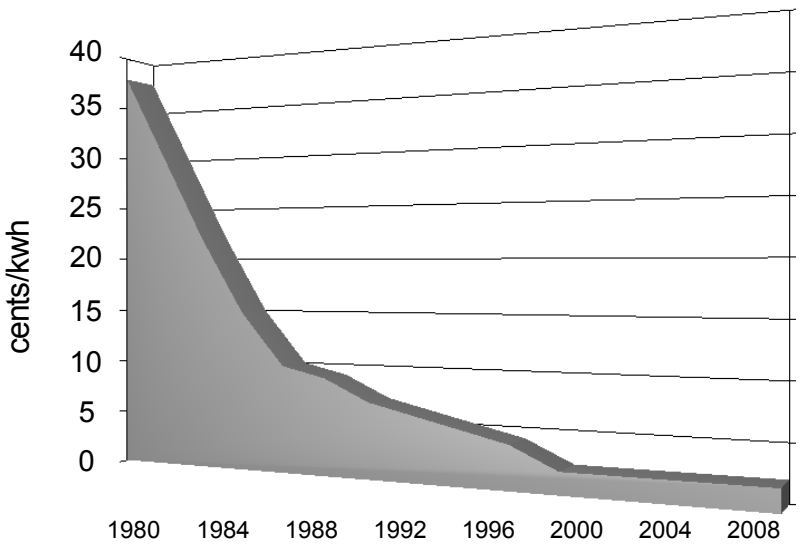


Figure 7. Since 1980 the costs of wind-generated electricity has dropped by more than eight-fold, to less than 5¢/kWh today. The goal of the Wind Energy Program is to bring costs down to 2.5¢/kWh.

Figure 8. The National Wind Technology Center's new Industrial User Facility was tailor-made for government/industry partnerships. The facility is designed to enable engineers and researchers to study and test wind turbine systems and components. It has office space for industry engineers, experimental laboratories, computer facilities, machine and wood shops, and a large blade-testing bay.

ly for wind turbines — rather than using airfoil shapes from airplane wings or helicopter rotors as had been done previously — NWTC engineers have improved the performance of the most common type of turbine by 23% to 35%.

Wind power is the one totally emission-free, non-hydroelectric energy technology that can economically compete for substantial contribution to the main U.S. electric power grid in the near future. Wind farms can now produce electricity for 4¢ to 5¢ per kWh in areas with ideal wind resources, approaching being competitive with new coal-fired plants. The basic goal of the DOE Wind Energy Program is to bring the cost down to 2.5¢ per kWh to be more competitive with all new electric plants, including natural gas turbines. At a fully competitive cost, wind power has tremendous prospects. One study says that North Dakota alone has enough suitable (high enough wind, low enough impact on other uses) land to provide one-third of total current U.S. electrical needs. Meeting the cost goals would also help America regain the lead in wind installations from Europe — which now has three times the capacity of the United States — and greatly improve the competitive position of U.S. manufacturers.

During the next five years, the NWTC will continue applied research in aerodynamics, structural dynamics and fatigue, power systems, and advanced concepts. A new initiative, Wind Partnerships for Advanced Component Technology (WindPACT), will become the focus of the applied research program in order to provide the innovative technology necessary for future generations of wind turbines, so that wind energy can be a cost-competitive supply of bulk electricity without subsidies.

During the next five years, NREL expects to:

- Complete testing of a 10-meter, research wind turbine in the NASA Ames wind tunnel
- Use a geographic information system platform to improve the wind resource database/forecasting system
- Develop a process for manufacturing advanced turbine blades
- Complete the development of 2.5¢/kWh next-generation wind turbine
- Demonstrate the potential for reducing the cost of energy by an additional 20% by testing the prototypes of two or three innovative components under WindPACT

Over the next decade, NREL will provide strategic support for DOE's Wind Powering America initiative announced by the Secretary of Energy in June, 1999. This is an initiative committed to dramatically increasing the use of wind energy in the United States. The initiative will establish new sources of income for American farmers and rural landowners, and help meet the growing demand for green electricity. The initiative will be a partnership of a variety of organizations from both the public and private sectors.

Currently, NREL is conducting detailed resource assessment studies of high-potential states; working with FEMP and DOE regional offices to aggregate federal loads and encourage the use of wind power for these loads; and conducting workshops in high-priority regions of the country, to encourage the use of wind power.

NREL has identified the need for upgrading its blade testing and dynamometer facilities to accommodate turbines greater than 2 MW, and to improve the safety of the entry to the National Wind Technology Center. These are discussed in the Operations & Infrastructure section.

Biopower

The objective of the U.S. Department of Energy Biopower Program is to work with industry to expand the use of biomass materials combustion for generating electricity and process heat. Materials such as forestry industry residues, agricultural residues, municipal solid waste, and "energy crops" can be combusted directly at industrial facilities or independent power producers or first converted to a liquid or gaseous fuel. Methane gas generated in landfills can also be captured and combusted. Unlike fossil fuels, because biomass materials are grown from atmospheric carbon dioxide on a short-term, continuing basis, they are fully renewable. The carbon dioxide released when they are combusted is balanced by carbon dioxide captured during their growth. To the extent that the biomass fuels are grown for energy production, biopower contributes little to net greenhouse gases.

Biopower is already by far the largest non-hydroelectric contributor to U.S. renewable energy generation. U.S. biopower capacity grew dramatically under the 1978 Public Utilities Regulatory Policy Act (PURPA) provision that guaranteed utilities would pay their avoided cost for surplus power from independent qualifying facilities. The majority of current biopower production is from small producers such as combined heat and power production at industrial facilities such as pulp and paper mills. Virtually all is generated with conventional direct combustion/steam turbine technology. With the recent expiration of PURPA contracts, technological advances to make biopower more efficient become more important.

NREL supports the DOE Biopower Program with research and development of thermochemical conversion technologies such as gasifying biomass for gas turbines, and with assessment and technical assistance for developing DOE-supported biopower projects. Specific current projects include work on small modular biopower generators, integrated biomass gasifier/generators, the chemistry of cofiring ash deposition, development of a portable system for monitoring thermochemical biopower systems, analytical support of the Vermont Gasifier, and life-cycle assessment of biopower processes.

During the next five years, NREL will expand its focus to include a full complement of efficient biomass power technologies, size ranges, and feedstocks (agricultural residues, wood residues, energy crops, etc.). NREL will also establish a balance between research and

Accomplishments in Biopower

- *1998 R&D 100 award for partnership of Battelle, Future Energy Resources Company, the Burlington Electric Department, and NREL for the Vermont High-Throughput Gasifier demonstration project*
- *Key technical and analytical support to five DOE cofiring and gasifier projects*
- *Life-cycle analysis of cofiring shows existing industry as a net sink for greenhouse gases and demonstrates environmental benefit of increasing biomass percentage*
- *Joint development of a revised strategic plan for biopower programs*
- *Analysis of biopower incentive policy proposals and of the contribution of biopower to greenhouse gas mitigation*
- *Development of an integrated biomass gasification diesel engine testing facility to provide gas-quality parameters to industry.*

Figure 9. At the McNeil generating station in Burlington, Vermont, an innovative, high-throughput gasifier converts biomass into gas for electric power generation. This technology won a 1998 R&D 100 Award for Battelle, Future Energy Resources Company, the Burlington Electric Department, and NREL.

Accomplishments in Concentrating Solar Power

- *New low-cost, high performance "commercial laminate mirror" and durable, flexible "super-thin glass" reflective materials developed for concentrating solar power*
- *USA-Trough program established to develop world-class products and services for CSP; five contracts have been awarded*
- *Identified reliability issues of distributed CSP; corrections are evaluated and tracked through a reliability database*
- *Began development of conceptual designs for smaller remote-power CSP applications*
- *Assistance to cost-benefit study of United Nations-World Bank-supported Global Environmental Facility's CSP grant program helped decision to maintain that $200 million program*

demonstration efforts to most effectively advance the technology.

During the next five years, NREL expects to:

- Complete testing of gasification/internal combustion system for a small modular system that makes biogas of a medium calorific value
- Successfully complete the shake-down testing of the Vermont Gasifier, integrating gasification-to-combustion turbine
- Initiate efforts for advanced modeling for combustion and cofiring, dynamic simulation and process control, and feedstock production
- Complete two Biomass Power for Rural Development projects with more than 100 MW of new biomass power generating capacity
- Complete the Cofiring Initiative with new facilities that were in the partnership. Facilities are cofiring biomass on a regular basis
- Complete the Small Modular Systems Initiative with two to three small-scale biomass systems poised for rapid commercialization by the private sector
- Complete the suite of life-cycle assessments relevant to biopower systems
- Generate 2 GWe (0.05 Quads/yr) from biomass and coal cofiring, offsetting 4 million metric tons of fossil carbon per year
- Operate five or more successful demonstration projects with animal manure as a fuel for electricity production as part of the Cooperative Agricultural Residues to Energy Initiative

Concentrating Solar Power

The DOE Concentrating Solar Power Program leads the national effort to develop clean, competitive, and reliable power options using concentrated sunlight. NREL uses staff from three different research areas to carry out the objectives of this program.

Concentrating solar power (CSP) technologies use mirrors to concentrate the sun's energy up to 10,000 times to power conventional turbines or heat engines to generate electricity. This clean, secure, environmentally friendly power diversifies our domestic electricity production options and has the potential for major impacts in international markets. Energy from CSP systems is high-value renewable power because energy storage and hybrid designs allow it to be provided on-demand — even when the sun is not shining.

Ranging in size from several kilowatts to multi-megawatt installations, CSP systems are expected to satisfy substantial domestic and international energy needs, contributing 5,000 MW by the year 2010. Consequently, CSP systems are also expected to make a significant contribution to the U.S. effort to reduce carbon emissions in the early part of the 21st century.

Figure 10. One of the technology pathways is represented by the Dish/Stirling system. The system uses dish concentrators to focus sunlight on a Stirling engine, a heat engine that uses the heat of the concentrated sunlight to drive a generator and produce electricity.

In response to the changes brought on by utility restructuring and the resulting emphasis on competition, the CSP Program has revised its focus from developing specific technologies to providing technology options to U.S. industry. This effort will enable industry to compete in near-term renewable energy markets and to further reduce costs, allowing for penetration of broader energy markets in the long term. The program's revised focus is reflected in three new program technology paths: distributed power, dispatchable power, advanced components and systems.

Future deployment of CSP technologies can substantially reduce greenhouse gas emissions. The rapid increases in annual production capacity achieved during the construction of existing plants (up to 80 MW/year) have demonstrated the capability of CSP production. Modest manufacturing capacity investment can rapidly expand CSP to provide huge quantities of power at prices that in the long term will compete directly with conventional fossil technologies. These technologies feature additional advantages of providing quality-manufacturing jobs for local economies and export markets for key components.

NREL supports the DOE Concentrating Solar Power Program and the CSP industry in the development of new designs and manufacturing processes for solar components and systems. With an increased emphasis on reliability and service life, NREL is developing and testing advanced optical materials, and designing new hybrid receiver concepts for dish/engine systems that will allow these technologies to extend operating hours through the use of fossil fuels. The program is developing a broader portfolio of technology options to meet the needs of the changing energy markets worldwide. NREL will assist DOE in focusing its CSP research efforts while continuing to collaborate with other DOE laboratories.

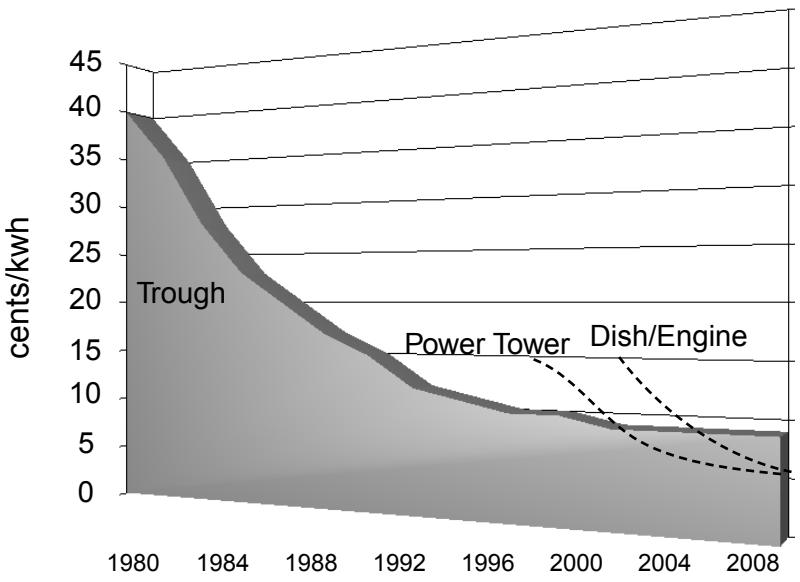


Figure 11. Since 1980 the costs of electricity generated with concentrated solar trough technology has fallen to nearly 10¢/kWh. With the expected advances in optical materials and concentrating systems, costs are expected to drop even more.

During the next five years, NREL expects to:

- Complete conceptual design for small-scale dish systems
- Develop detailed designs for a dispatchable power plant capable of achieving solar energy costs of 0.10¢/kWh or less
- Evaluate the feasibility of system designs for remote power applications

Solar Buildings

Established within OPT in FY 1997, the DOE Solar Buildings Technologies Program has a mission to advance the development and widespread deployment of competitive solar technologies for use in buildings in both domestic and international markets. The NREL Solar Buildings Program specifically researches and develops technologies that produce thermal energy for the buildings sector and that also have the long-range potential to become an integral part of a pollution-free building that generates its own energy.

Accomplishments in Solar Buildings

- *Facilitated an innovative solar water heating pilot project in which a Florida utility installs solar water heaters on individual customers' homes and then meters and sells the energy delivered from them*
- *Developed a multiyear program plan for investigating use of low-cost polymer materials in solar water heating systems; issued a series of contracts to industry and university research teams for carrying out the plan*

The program's solar heat focus is driven by the need for thermal energy for water heating, space heating, and space cooling applications. Researchers within the program are working on a range of solar thermal technologies that generate hot water and heated air for residential and commercial use. The program works closely with manufacturers in the buildings and solar energy industries and supports research at universities as well as national laboratories to bring together the diverse players developing reliable, economically viable solar thermal technologies for building applications.

NREL and Sandia National Laboratories work jointly to carry out the DOE Solar Buildings Program. Approximately half of the FY 2000 budget is allocated to subcontracted research and about one-third to NREL in-house research. NREL's current activities are directed primarily towards a goal of cutting the cost of delivered energy in half by FY 2003 for solar hot water systems. Work is focusing on the use of low-cost polymer materials in solar hot water systems, which is seen as one of the most promising avenues for achieving this goal.

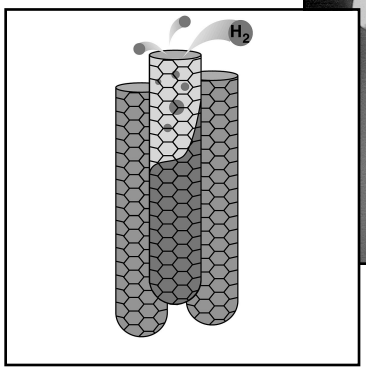


Figure 12. In the long term, hydrogen will be produced from renewable resources (such as with sunlight, photoelctrochemical devices, and water, as shown in the photo) and stored in carbon nanostructures (as depicted in the schmetic).

During the next five years, NREL expects to:

- Formulate concepts and design specifications for "zero energy" buildings — buildings that have all of their energy needs provided economically by solar technology
- Select innovative, low-cost concepts and materials for the development of the "next generation" of solar systems for water and space heating
- Work with solar industry partners to develop and test field-scale prototypes of low-cost system designs
- Continue outdoor and ultra-accelerated durability testing of polymer glazings, absorbers, and coatings
- Work with polymer manufacturing specialists to refine the low-cost system designs and their manufacturing process

Hydrogen

The DOE Hydrogen Program researches and validates development of safe, cost-effective hydrogen energy technologies that support and foster the transition to a hydrogen economy. In order to enable a future that includes hydrogen energy, the DOE Hydrogen Program supports a strong core effort, including near-, mid-, and long-term strategies. The overall program goal calls for making a transition to a hydrogen-based economy, with the expectation that in the long term hydrogen will join electricity as a major energy carrier and that much of that hydrogen will be derived from renewable energy resources. As the lead DOE laboratory for renewable hydrogen production technology, NREL researches many facets of hydrogen including production by photoelectrochemical, photobiological, and thermochemical conversion technologies.

Hydrogen — the most plentiful element in the universe — is the ideal fuel. Whether oxidized in

a fuel cell, combusted in a conventional engine, or simply burned, its only byproduct is water. As a transportable fuel, it has greater flexibility than electricity for transportation vehicle and remote area use, so many see it as the basis for the total energy economy of the future. In addition to researching a variety of means for producing hydrogen with renewable energy, NREL scientists are developing innovative technologies for purifying, storing, sensing, and using hydrogen.

NREL serves as the lead lab for renewable hydrogen production technologies, as well as serving as a leader in advanced storage and sensor development. Basic and applied research and material development using biology, physics, and chemistry enable and support the development of hydrogen production, storage, and end-use systems. Design and testing of system components, and process and systems analysis, provide direction, focus, and support to the development and introduction of hydrogen technologies. Strategic planning and analysis provides timely, accurate, insightful, and forward-thinking analysis of the most important hydrogen opportunities and issues. During the next five years, NREL intends to significantly expand its collaborations with other DOE laboratories and universities in hydrogen research that complements NREL efforts.

During the next five years, NREL expects to:

- Design and construct a process development unit for bio-oil reforming, using the existing Thermochemical User Facility for larger-scale experiments
- Isolate hydrogen-producing algal mutants with enhanced oxygen tolerance at 5% oxygen for 10 minutes
- Develop 5% efficient nitride-based materials for photoelectrochemical water splitting
- Store 10 grams of hydrogen at 6 wt% and room temperature in a system based on carbon nanotubes
- Prepare an analysis of the feasibility of establishing a National Hydrogen R&D Center that would be an international focal point for basic and applied R&D and serve as the coordinating center for a network of highly integrated R&D projects
- Construct and operate a microbial water-gas shift pilot plant
- Evaluate the commercial promise of NREL/UCB algal hydrogen production system
- Perform a detailed life-cycle assessment of hydrogen production system
- Develop and enhance hydrogen investment strategy
- Develop the necessary codes and standards for the introduction of hydrogen technologies
- Lead coordinating committee on emission and performance testing of hydrogen vehicles

Geothermal Energy

The mission of the DOE Geothermal Energy Program is to work in partnership with U.S. industry to establish geothermal energy as an economically competitive contributor to the U.S. energy supply. NREL works to achieve this mission by applying its expertise in advanced heat transfer technologies to improve the performance of geothermal power plants. The Laboratory collaborates with industry to improve the economics of electricity production from low- to moderate-temperature geothermal resources by increasing plant cycle efficiency, optimizing plant design, improving components, and lowering operation and maintenance costs. Geothermal energy consists of heat that flows continuously from the Earth's core toward the surface. Geological processes concentrate enough of that heat near the surface that a large amount of energy could be extracted for productive use. Geothermal energy can be used for electrical power generation, for geothermal heat pumps, and for direct applications such as district heating, greenhouse heating, and aquaculture — all on a clean, reliable, and sustainable basis.

Accomplishments in Hydrogen

- *Advances, scale-up, and testing of two different design bioreactors for producing hydrogen from biomass with bacteria performing a carbon monoxide shift reaction*
- *Licensing for commercial production of hydrogen sensor technology that could be highly valuable to safe operation of future hydrogen systems*
- *Completed cradle-to-grave life-cycle assessment of the steam methane reforming process; this will serve as a base case for analysis of renewable energy technologies for producing hydrogen*
- *Hydrogen program scenario planning under the auspices of the Hydrogen Technical Advisory Panel kicked off with a successful workshop at NREL*
- *Publication in Nature of an article on the discovery of the ability to store — at higher temperatures, at much greater density, and more safely — hydrogen in microscopic carbon nanotubes*

Accomplishments in Geothermal Energy

- *1999 R&D 100 award jointly with licensee Alstom Energy Systems for Advanced Direct Contact Condenser technology that greatly improves efficiency and reduces the cost of emission abatement geo thermal power plants*
- *New air-cooled condenser technology developed that improves efficiency by 30% for binary-cycle geothermal plants; patent application in progress*

Nearly all current geothermal energy use comes from hydrothermal resources where there are reservoirs of water or steam that have been heated by contact with hot rock. To reap the full potential of geothermal energy, it will be necessary to develop cost-effective technology for directly tapping the energy of deeper, dry, hot rock where water is not present naturally, as well as to improve the efficiency of hydrothermal resource use.

The Geothermal Energy Program has established the following goals:

- Supply the electrical power or heat energy needs of 7 million U.S. homes and businesses by 2010
- Reduce the levelized cost of geothermal power to 3-5¢/kWh by 2007
- Double the number of states with geothermal electric power facilities to 8 by 2006

NREL contributes to these goals by improving the efficiency of heat transfer of geothermal technologies, by serving as a core laboratory for energy systems research and testing (including advanced plant systems), and through education and outreach activities and analysis of economic issues. During the next five years, NREL intends to significantly expand its geothermal research collaborations with other DOE laboratories and to:

- Use field test results to identify the best lining material for heat exchangers
- Complete tests of advanced condenser designs for use with ammonia-water working fluid
- Complete laboratory tests of innovative thermodynamic cycles that employ mixed working fluids
- Complete field tests of a prototype high-performance air-cooled condenser

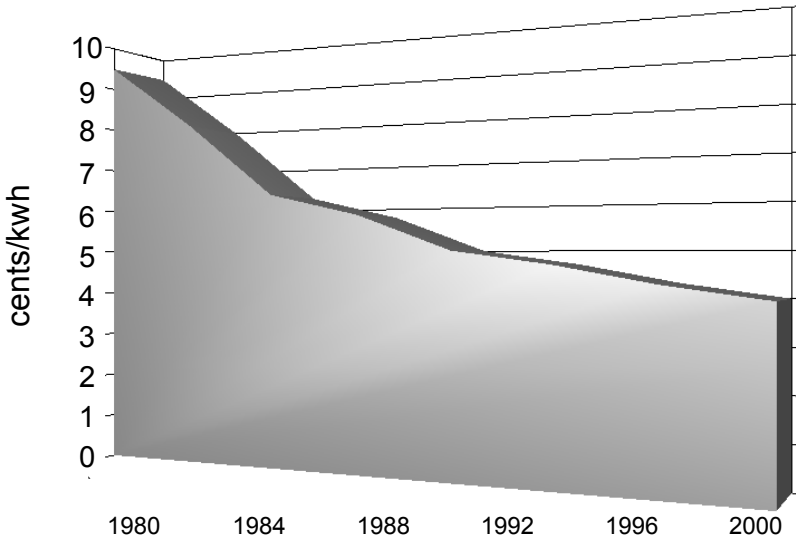


Figure 13. The cost of geothermal electricity has decreased by more than 50% since 1980 — to about 4¢/kWh.

Distributed Power

With the restructuring of the electric power industry, the growing competition in the industry, the advance of small, modular generation technologies such as photovoltaics, fuel cells, and microturbines, and increasing consumer choice, DOE established a Distributed Power Program (DPP) in FY 1999.

As the designated lead laboratory for this program, NREL supports DOE's goal to have full-valued distributed power available in an electricity market in which customers can sell power, employ load management, and provide operations support services in an automated and adaptive electric power system.

Industry has said that its number one priority is to remove the barriers to interconnection with the electric power grid that exists today. What is needed is a nondiscriminatory national standard that applies to all distributed power technologies and assures that these systems are properly integrated into the grid in a manner that addresses critical safety, reliability, and power-quality issues. Modeling and analysis of distributed power system integration, the conduct of hardware tests to verify performance of interconnection standards, and the development of a certification process for distributed power and

interface equipment are needed to support the development and implementation of this standard. To realize the full potential of distributed power in the marketplace requires the development of model ordinances and national building and safety codes for distributed power, as well as regulatory and business environments that do not create unnecessay barriers to these technologies. The creation of standardized families of modular "plug and play" interconnection hardware and software will simplify the interconnection of distributed generators and storage systems certified to operate with these interconnection devices, so that any home or business desiring on-site power will be able to install it as easily as installing a new furnace.

To address these and other issues, the DOE DPP will conduct R&D in three principal areas:

- Strategic research. The program will address operational concepts for distributed power that would be enabled by advanced system control technologies needed to safely integrate small modular generation and storage technologies such as fuel cells, micro-turbines, photovoltaics, wind, batteries, and flywheels into the distribution system.The program will also conduct research on advanced hardware and software technologies for interfacing with the power system.
- Systems integration. The program will identify issues (safety, reliability, interconnection, power quality, etc.) related to the integration of distributed generation and storage into the electrical system, and will provide solutions through applied engineering research, analysis, testing, and leadership in facilitating and developing technical standards and codes.
- Institutional issues. The program will examine the implications that current practices, planning methodologies, policies, regulations, ownership structures, and other institutional issues have for distributed power applications. The program will also work with industry and state and local governments to reduce institutional and infrastructural barriers to the deployment of distributed power systems.

NREL supports the DPP in many ways. Specifically, over the next five years NREL expects to:

- Initiate research projects in system interconnection, reliability, and safety, as mandated by Congress
- Initiate the Nevada test site demonstration project for DPP
- Facilitate the development of the IEEE interconnection standard for distributed power
- Design and initiate distributed power system(s) model development and validation through systems analysis and field testing
- Assess and develop standards and codes effecting distributed power utilization, siting, and cost
- Conduct regional field testing of distributed power on radial grids at the distribution level to determine the effectiveness of interconnection technologies and the need for further enhancements

Superconductivity

Superconductivity is the ability of certain materials to conduct electricity with essentially no resistive losses, which offers significant improvements in energy efficiency for electric power applications. Previous work on applying superconductivity to power applications was compromised by the requirement for liquid helium cooling at 4.2 K, which resulted in high losses for refrigeration and major questions on reliability. The operating costs and engineering problems for cooling and insulating these "liquid helium" low–temperature superconductors provided a strong impediment to utility customers considering the use of superconducting power devices.

Accomplishments in Superconductivity

- *Demonstrated several qualities of thallium oxide films and capabilities for producing them that should prove highly valuable to the ability to use superconducting tapes for ultra-low-resistance-loss electrical transmission*
- *Current density maintained with films ranging from 0.8 microns to 2.6 microns thick*
- *Current density greater than 106 A/cm^2 with strontium and bismuth doping*
- *Reproducible growth of buffer on single-crystal substrates*

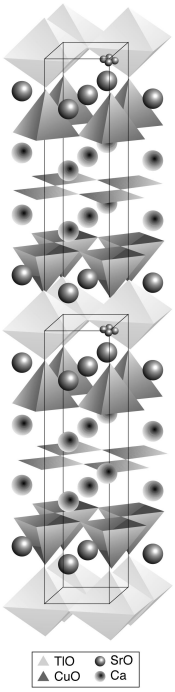


Figure 14. Atomic structure of single-layer, thallium-based high-temperature superconducting material being investigated by NREL. The material has a high transition temperature and promising superconducting properties.

The discovery of high–temperature superconductivity (HTS), in 1986, offered the ability to operate superconducting devices at much higher temperatures using fairly inexpensive refrigerants such as liquid nitrogen at about 77 K. The ability to use HTS would thus be more economically attractive and would significantly ease cryogenic design and refrigeration. This discovery initiated a high-stakes race to apply HTS technology. To help U.S. industry develop HTS technology, the DOE created the Superconductivity for Electric Systems Program in 1988. Industry, in turn, is developing and commercializing electric power applications of HTS. The program combines the entrepreneurial drive of high-tech companies with the vast technological resources of NREL and other DOE national laboratories.

Over the past few years the use of HTS has been pursued for a wide range of electric power applications with emphasis on motors and generators, underground transmission cables and fault-current limiters and transformers for distribution substations. The major issue for the successful demonstration of an HTS power device is the fabrication of a cost-effective wire or tape with the required performance to carry sufficient current at technologically useful magnetic fields at temperatures within the liquid nitrogen range.

The introduction of HTS within the electric power sector offers the potential for components that are more efficient, smaller in size and weight, and exhibit performance advantages over their conventional counterparts.

The primary focus for the NREL superconductivity program has been the development of a practical wire or tape using thallium (Tl) oxide superconductors. The Tl-oxides provide inexpensive processing approaches and benefit from high superconducting transition temperatures near 125 K and magnetic properties at 77 K. Following the start of the DOE superconductivity program in 1988, NREL pioneered a unique processing approach using electrodeposition. Since then, NREL has refined and extended the electrodeposition method to directly produce high-quality thick films that can be implemented in a high-rate, cost-effective thick-film tape process. NREL is currently working with Oak Ridge National Laboratory and with universities to apply our unique processing approaches to the demonstration of a biaxially textured thick-film tape of the single layer Tl-1223 compound on a buffered textured metallic substrate. If successful, this tape should offer lower cost and superior performance to alternative candidates under development.

During the next 5 years NREL will continue to develop thallium oxide superconductors in a wire or tape configuration suitable for application to power–related components. NREL will concentrate on the demonstration and commercial scale-up of the single–layer Tl com-

pounds using thick–film-processing methods such as electrodeposition and spray techniques. The successful development of a long length biaxially textured Tl-1223 tape will provide a cost effective HTS conductor with technologically acceptable performance.

NREL will also continue to provide technical support for DOE's Superconductivity Partnership Initiative (SPI) and help DOE monitor the SPI programs.

NREL will also work closely with the renewable areas such as wind and photovoltaics to develop a renewable oriented energy storage program with high turn-around efficiency and high reliability that will facilitate the integration of renewables into grid and stand-alone installations.

Energy Analysis

NREL conducts technology and applications analyses, and market and benefits analyses for the Office of Power Technologies and many of its individual programs. In addition to NREL and DOE, the customers for these analyses include numerous stakeholders in the energy sectors and numerous decision-makers at the federal, state, and local levels, as well as private sector firms and institutions involved with energy systems.

One of our primary areas of focus is on the analysis and tracking of the developing green power markets nationwide. In addition to maintaining a green power network on the internet, we work with utilities, states, and green power providers to further this market. We also track the impact of electric sector restructuring on renewables. Another of our current emphases is our collaboration with the Energy Information Administration (EIA) to improve the representation of renewable energy technologies in its National Energy Modeling System, which will help EIA make more credible projections of the future contributions of renewable energy in its studies and analyses.

During the next five years, NREL will continue its analysis work, placing increasing attention on emerging areas such as deregulation and distributed power. NREL wil also develop a Clean Energy Analysis capability (see page 37 for more on this capability).

Office of Transportation Technologies

The mission of EERE's Office of Transportation Technologies is to work with the domestic transportation industry, energy supply industry, and research and development organizations to develop and promote the use of advanced transportation vehicles and alternative fuel technologies that will reduce oil imports and reduce the emission of pollutants and greenhouse gases; and to develop a strong technology base to enable the transportation industry to sustain a strong competitive position in domestic and world markets. NREL supports this mission by managing programs and projects and performing R&D in biofuels (fuels derived from biomass), fuels utilization, and advanced automotive technologies.

Biofuels

The primary goal of the DOE Biofuels Program is to develop cost-effective, environmentally friendly technologies for producing alternative transportation fuels and fuel additives from plant biomass. NREL is currently pursuing two projects in support of this program: biomass ethanol and biodiesel (methyl esters of common vegetable and animal fats).

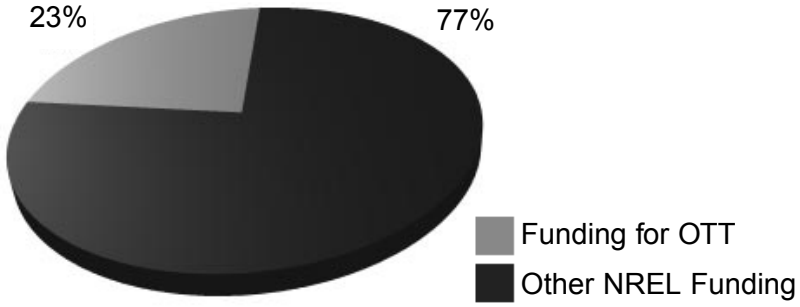


Figure 15. EERE's Office of Transportation Technologies funded 23% of NREL's activities in FY 1999, which included work in biofuels, fuels utilization, and advanced automotive technologies.

Accomplishments in Biofuels

- *Cellulase enzymes improved so that smaller amounts are needed for biomass ethanol fermentation, reducing cost for enzymes by nearly 30%*
- *Additional advances, including successfully integrating seven necessary genes, made in the metabolic engineering of NREL's xylose- and glucose-fermenting Zymomonas mobilis*
- *Innovative countercurrent pretreatment reactor for biomass installed and verified at engineering scale*
- *Biofuels Program Plan completely revised and database on milestones and subcontracts created*
- *Several important projects completed in cooperation with the corn processing and ethanol industries, helping to build a bridge toward creating a base for future biomass conversion capabilities*

The domestic supply of conventional petroleum is the most limited of the country's major energy sources. The U.S. transportation sector is almost totally dependent on petroleum, making the nation highly vulnerable to an interruption of oil supply or an increase in price. The United States now imports about 55% of its oil supply at a cost of almost $60 billion annually — the biggest contribution to the foreign trade deficit.

Use of biofuels, made by converting domestically grown plant materials — biomass — into liquid fuels suitable for transportation, not only avoids the dependency and associated job loss of oil imports, but supports U.S. agriculture and new biofuels industries and has major environmental benefits. For example, as biomass grows, it captures carbon dioxide — unlike oil and other fossil fuels where this process happened millions of years ago — balancing the carbon dioxide released when biofuels are burned, which helps alleviate greenhouse gas buildup. Also, ethanol made by fermenting cornstarch, which is widely used in this country as an oxygenating fuel additive to boost octane, reduces carbon monoxide and hydrocarbon emissions. And biodiesel, made by chemically transforming fats or oils, is extensively used in Europe to reduce sulfur and particulate emissions from trucks.

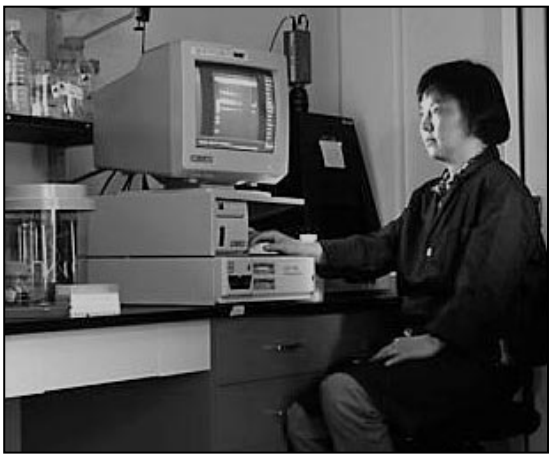


Figure 17. Researcher views computer display of DNA extracted from NREL's metabolically engineered Zymomonas mobilis, used to ferment zylose and glucose for alcohol fuels. This technology won an R&D 100 award.

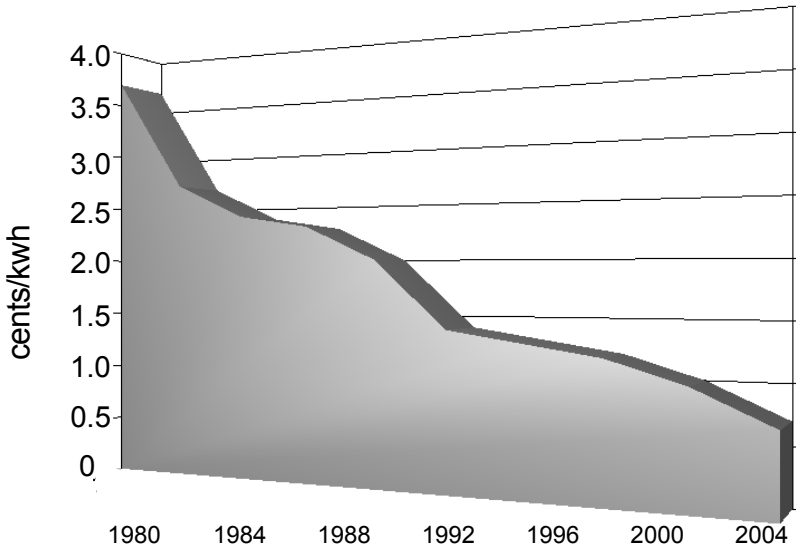


Figure 16. In 1980 it cost $3.60 to produce a gallon of ethanol; today it costs $1.20. With favorable feedstock supplies and with continued advances in metabolic engineering of cellulase enzymes and in reactor technology, the cost of ethanol production is expected to drop below $0.70 per gallon.

The challenge of biomass ethanol is to develop technology to cost-effectively use the inexpensive cellulosic (fibrous) material that makes up most of plant material instead of relatively expensive food crops such as sugar or cornstarch. The Ethanol Project at NREL focuses on three major DOE national program goals:

- The commercial production of ethanol from a low-cost lignocellulosic residue by the end of the year 2000
- The commercial production of ethanol utilizing switchgrass and agricultural residues by the end of the year 2005
- The commercial production of ethanol from biomass utilizing technology that eliminates the need for the ethanol tax incentive. Specifically, the target is to produce, by the year 2015, ethanol for 70¢/gallon from feedstock that costs $35/ton.

NREL supports the rapid commercialization of bioethanol from low-value feedstocks by col-

laborating with industrial partners having the best business plans, access to capital, and most favorable feedstock supplies. Several highly promising projects are planned for FY 2000. To reduce the cost of bioethanol production to be competitive with petroleum derived fuels, NREL will concentrate on the following tasks:

- Development of improved specific-activity cellulase enzymes
- Development of an efficient enzymatic conversion process technology
- Development of improved ethanol-producing microorganisms
- Development of the counter-current pretreatment technology
- Conversion of residual lignin to liquid fuels.

NREL Biodiesel Project activities support the emergence of renewable diesel fuels in the marketplace by:

- Reducing the cost of renewable diesel fuels by developing low-cost feedstock
- Characterizing renewable diesel fuels
- Conducting program planning, outreach, technology transfer, and market development.

During the next five years, NREL expects to:

- Confirm the feasibility of, or close out, the countercurrent pretreatment reactor process using the minimum-scale engineering reactor
- Develop updated performance data for the enzymatic conversion of switchgrass to ethanol
- Begin the development of corn stover-to-ethanol conversion technology with an industrial partner
- Demonstrate the feasibility of the conversion of switchgrass to ethanol with an industrial partner
- Move corn stover-to-ethanol process into engineering phase with an industrial partner
- Quadruple cellulase enzyme specific activity relative to T. reesei enzymes

Fuels Utilization

NREL's Fuels Utilization (FU) program provides the DOE with technical leadership and expertise in (1) technologies involving motor fuels, engines, emission control, and vehicle systems; (2) studies developing a sound understanding of the environmental effects of transportation emissions; and (3) deployment of technology into the market place. The goals of the FU program are to assist DOE in (1) implementing parts of the Alternative Motor Fuels Act (AMFA) and the Energy Policy Act (EPAct), and (2) conducting projects to develop advanced transportation fuels and vehicle systems optimized for their use. NREL assists DOE in defining an appropriate program to meet its goals pertaining to the utilization of new transportation fuels; serves as a focal point for DOE in all advanced fuels utilization activities; and serves as DOE's repository for all alternative fuels utilization information through the Alternative Fuels Data Center (AFDC). The FU program pursues its goals through four strategic thrusts:

- Advanced Transportation Fuels Research and Development

Accomplishments in Fuels Utilization

- *Alternative Fuels Data Center Web site completely redesigned to include more information on medium- and heavy-duty vehicles and to allow alternative fuel fleet managers to share experiences*
- *NREL staff were appointed to serve on several key air quality and vehicle committees, affirming NREL's role as an important player in the automotive and environmental sectors*
- *NREL led a major government-industry study on the relation between sulfur in diesel fuel and advanced emission control technologies*
- *NREL's program in alternative fuels led to three heavy-duty natural gas engines being certified to emission standards, and to a dimethyl ether fuel supply pump being efficient and durable*

Figure 18. NREL works with industry partners to research and test cool car concepts. This Plymouth Breeze is a "cool car" with electrochromic windows, heated and cooled seats, and boundary layer control.

- Environmental Science and Health Effects
- Advanced Technology Vehicle Development, Evaluation, and Deployment
- Information Development and Dissemination

Under Advanced Transportation Fuels R&D, NREL develops and evaluates advanced fuels for use in internal combustion engines and fuel cells. Advanced fuels include "gas-to-liquid" synthetic fuels, renewable fuels, alcohols, oxygenates, blending agents, and fuels derived from crude oil. NREL also develops technologies to enable the use of advanced liquid and gaseous fuels, including: onboard fuel storage, fuel delivery and injection systems, fuel reforming, fuel charge pre-treatment, and emission control devices.

Under Environmental Science and Health Effects, NREL establishes a scientific basis that accurately describes the contribution of vehicle emissions to both atmospheric and public health effects. Under Advanced Technology Vehicle Development, Evaluation, and Deployment, NREL enables streamlined on-road development, testing, and evaluation of prototype advanced technology vehicles (ATVs) and alternative fuel vehicles (AFVs).

Figure 19. As part of its work in cooperation with industry on hybrid electric vehicles, NREL models, tests, and analyzes thermal management for cutting-edge battery technologies.

Under Information Development and Dissemination, NREL develops, organizes, evaluates, and disseminates information and tools to help people make informed decisions about purchasing AFVs and ATVs. NREL also supports DOE's Clean Cities program and DOE's regulatory program for EPAct compliance.

NREL works with leading energy companies and manufacturers of vehicles and engines to develop advanced moter vehicle fuels for improved energy and environmental performance. The goal for the next five years is to identify optimal motor fuels that will enable advanced vehicle technologies to meet emission standards for the 2004-2010 time frame, while reducing dependence on imported petroleum.

Over the next five years, NREL will:

- Develop advanced petroleum-based fuels for the next generation of compression ignition engines that will enable these engines to meet DOE's goals for operation at high efficiency and to meet future emission standards
- Test advanced engine systems for natural gas and optimize them for heavy-duty engines
- Develop optimized engine management/ fuel/emission control technologies
- Develop a sound understanding of the relative role of gasoline and diesel vehicle exhaust to ambient levels of particulate matter, ozone, and regional haze
- Assist DOE in catalyzing the market penetration in advanced technology vehicles through regulatory support and matching DOE Clean Cities infrastructure programs to federal and other fleet concentrations
- Complete a collaborative study to understand the causes of high weekend ozone concentrations in urban areas
- Develop and optimize advanced fuels and lubricants for the next generation com-pression ignition engines and their emission control systems

Advanced Automotive Technologies

NREL supports the DOE advanced automotive technologies goals primarily with work for the Hybrid Electric Vehicle (HEV) Program. DOE established the first Electric and Hybrid Vehicle Program in response to the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976. The act authorized the Department to "encourage and support accelerated research into, and development of electric and hybrid vehicle technologies."

HEV research and development is a key component of DOE's Advanced Automotive Technologies Program and is focused on developing production-feasible hybrid vehicle technologies by 2004 that will enable subsequent market introduction of an 80-mpg light-duty vehicle.

Hybrid Electric Vehicles combine the heat engine and fuel tank of a conventional vehicle with the battery and electric motor of an electric vehicle. This combination offers the extended range and rapid refueling that consumers expect from a conventional vehicle, with a significant portion of the energy and environmental benefits of an electric vehicle. The practical benefits of HEVs include the capability of using petroleum or alternative fuels, and improved fuel economy and lower emissions compared to conventional vehicles.

During the past several years, NREL has used its core expertise working with original equipment manufacturers (OEMs) and suppliers in battery thermal management, component and subsystem optimization, structural engineering, advanced vehicle modeling, and vehicle climate control. In FY 1999, NREL successfully concluded its subcontracts with OEMs GM, Ford, and Daimler Chrysler. As a result of it's working relationship with the OEMs and many of their lower-tier suppliers, NREL has gained a detailed look into the approaches and tools that are routinely used when developing new technologies and innovations for mass-produced automobiles.

During the next five years, NREL expects to:

- Develop functional specifications for the next-generation medium and heavy-duty natural gas vehicles through a government-industry working group and initiate development
- Demonstrate the systems analysis toolkit ADVISOR with seamless links to other math-based tools, and use it to assist industry with advanced vehicle development
- Develop a prototype natural gas engine and fueling system with drop-in capability for Class 3-6 propulsion systems
- Develop and test an optimized systems design for a vehicle climate control system that reduces energy use by 50%
- Develop two prototype, next-generation, medium- and heavy-duty natural gas vehicles that are fully comparable to diesel-powered vehicles

NREL works hand-in-hand with industry to develop advanced vehicles and systems for transportation, to develop viable vehicle systems that are aligned with the goals of Partnership for a New Generation of Vehicles and of other DOE transportation initiatives.

NREL will assist industry with developing high-energy efficiency vehicles from a systems-level perspective, including digital functional vehicle and validation of total vehicle energy and emission management that have significant impacts, such as vehicle climate control and battery thermal management. In addition, NREL will begin work on the next generation of heavy natural-gas vehicles to help industry produce prototypes of these vehicles. NREL will concentrate its efforts on developing real-world technologies for industry that can be implemented in vehicles in the near term.

Accomplishments in Advanced Automotive Technologies

- *Tested hybrid vehicles for Ford and Chrysler and tested a commercial Toyota hybrid vehicle under an industry bench marking activity*
- *Continued partnerships with major U.S. car manufacturers for advanced fuel, hybrid, and other advanced vehicle technologies*
- *Used ADVISOR program to demonstrate "Virtual Vehicle" models for hybrid and fuel-cell vehicles, thus providing quick and inexpensive testing of technologies for incorporation into advanced vehicle designs*
- *Modeled four competing, cutting-edge battery technologies and analyzed their thermal management, which showed their strengths and weaknesses and which enhanced ADVISOR's modeling abilities*
- *In close cooperation with industry, tested "Cool Car" vehicle climate control technology, setting the stage for great efficiency gains from reduced need for air conditioning*

Accomplishments in Building Technologies

- *Staff members completed work on more than 1258 energy-efficient houses as part of the Building America project, exceeding their FY 1999 goal of 700 houses.*
- *Building America houses with new, smaller air-conditioning systems were found, in energy performance tests, to perform 30% to 75% better than conventional homes; smaller systems could be installed because the houses' other features reduced the cooling demand.*
- *For its industry partners, NREL identified design and material options for advanced desiccant cooling systems; these cooling systems remove moisture from the air at least three to five times faster than conventional air-conditioners do.*
- *The Office of Management and Budget has adopted NREL's method of conducting consumer analyses of the impacts on consumers of new efficiency standards for certain large appliances, such as clothes washers.*
- *In 1998 and 1999 NREL received an ASHRAE Technology Award for outstanding achievement in the design and operation of energy-efficient buildings; an R&D 100 Award for an advanced, direct-contact condenser; an Electrochemical Society award to NREL scientist Dr. Al Czandera for his outstanding contributions to solar research; and a Lifetime Achievement Award from the Passive and Low-Energy Architecture group to NREL engineer Dr. Doug Balcomb for his long-standing contributions to the field.*

Office of Building Technology, State and Community Programs

The EERE Office of Building Technology, State and Community Programs (BTS) supports the energy needs of the buildings sector of the economy. In partnership with business and the government, BTS develops, promotes, and integrates energy technologies and practices to make buildings more efficient and affordable and communities more livable. The goals of BTS are to reduce energy use in the buildings sector by 2 quads per year by 2010 and by 5 quads per year by 2020. The strategy for achieving these goals is three-pronged:

- Accelerate the introduction of highly efficient technologies and practices through research and development
- Increase the minimum efficiency of buildings and equipment through codes, standards and guidelines
- Encourage use of energy efficiency and renewable energy technologies and practices through technology transfer and financial assistance.

Figure 20. The Thermal Test Facility is used to simulate and test the performance of building materials and fabricated components. This facility is a state-of-the-art laboratory containing advanced testing capabilities for the investigation of building physics, components, and systems, by both NREL and industrial researchers.

NREL supports the BTS by conducting research in heat transfer, thermal dynamics, and systems engineering. NREL researchers and engineers also work with industry to develop new building designs, technologies, and appliances that increase the overall energy efficiency of both residential and commercial buildings. In addition, the Laboratory's research teams help to develop advanced renewable energy technologies that can be integrated into "whole-building" design approaches to reduce both energy costs and the greenhouse gases associated with burning conventional fossil fuels for heat and electricity. Specifically, NREL's researchers focus on the following areas:

- Residential and Commercial Buildings — NREL continues to support DOE's Building America programs by working with the U.S. home-building industry to develop quality homes that consume 30% to 75% less energy than conventional homes do; this is on target to meet the DOE BTS goal of a 50% average improvement in energy performance for residential buildings.

  In addition, NREL develops high-performance, whole-building designs that integrate energy-efficient practices and products, such as energy-efficient light fixtures, with renewable energy technologies, such as solar water heating, for both residential and commercial buildings. Staff working on passive solar building designs take a similar whole-building approach that encourages the use of renewable energy systems in concert with energy-efficient and passive solar features, like south facing, double-pane windows.
- Building Technologies — NREL's researchers work with industry to evaluate and test advanced desiccant cooling and dehumidification systems and to develop prototypes.

They are also working with other groups at NREL, within DOE, and in industry to develop building-integrated photovoltaic (BIPV) systems, such as electricity-producing roofing materials, that are part of the structure itself. Other researchers are evaluating and testing electrochromic or "smart" windows, which save energy by controlling heat gains and losses through a building's fenestration system.

- Analysis and Evaluation — NREL's specialists are continuing to develop and refine a number of sophisticated design and analysis tools that model buildings' energy performance; these tools assist architects in designing cost-effective, energy-efficient structures. The modeling tools, many of which have won national awards, include Energy-10, BESTest, and SUNREL. Staff also continues to develop new codes, standards, and guidelines for buildings, building equipment, and energy-efficient appliances.
- Communications — NREL's communications specialists work hand-in-hand with the BTS contacts to develop and refine BTS' communications strategy. Our communications teams develop and maintain a variety of products for BTS, including the BTS Web site, the quarterly BTS newsletter, and a wide range of other electronic and hard copy products.

Work in support of building technologies and state and community programs will assist in moving the nation closer to achieving the aggressive goals established by DOE BTS in FY 1999. DOE BTS and its government-industry partners, including NREL, plan to achieve these goals by aggregating and focusing numerous buildings-related programs and by establishing clear priorities among them.

In its strategic plan, "Buildings for the 21st Century," DOE BTS describes the following major objectives:

- Establishing stronger and more effective partnerships with industry and the states
- Working with partners to develop government-industry technology road maps
- Establishing a culture of competitively selected, peer-reviewed projects
- Integrating the development of cost-effective, technology-based, energy-efficient products and practices
- Creating an organization that is customer-focused, highly productive, and results-driven.

NREL plans to support these objectives in all its relevant research, development, and deployment activities. During the next five years, NREL also plans to:

- Explore options for net-generating buildings and the potential for creating synergies with transportation needs
- Improve the reliability of electrochromic window systems so that large-scale demonstrations can begin with industry partners
- Create innovative building energy systems, including renewables, for adoption by builders on a production basis, and partner with multiple builder groups incorporating energy-saving innovations in approximately 8,000 houses
- Develop and demonstrate low-energy, desiccant-based dehumidification systems for hot and humid climate regions
- Begin, with industry partners, to develop the next generation of electrochromic technology

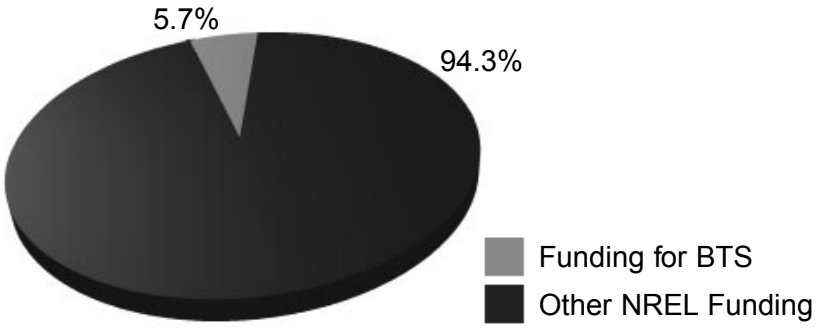


Figure 21. EERE's Office of Building Technology, State, and Community Programs funded 5.7% of NREL's activities in FY 1999, to develop and promote ways in which to make buildings more efficient and affordable.

Accomplishments for OIT

- *1997 R&D 100 Award to NREL and its DOE and industrial partners for process for producing valuable chemicals from biologically derived succinic acid*
- *1999 Green Chemistry (EPA/White House) Award to NREL and its DOE and industrial partners for process for making valuable chemicals from levulinic acid made from biomass materials*
- *Continued accolades and progress for NREL technology for wood characterization with near infrared spectroscopy for the pulp and paper industry, including a ninth industrial sponsor and the first Industries of the Future award to a DOE lab staff member*
- *Demonstration of the near infrared spectroscopic technology for characterizing mechanical as well as chemical properties of wood*
- *Industrial partner Eastman Chemical scaling-up NREL clean fractionation process for producing cellulose pulp more cleanly and efficiently than current technology*
- *Major contributions to OIT/industry strategic planning and information dissemination including roadmapping efforts, conference and exposition organization, Web site redesigns, and a corporate video*

Office of Industrial Technologies

The Office of Industrial Technologies (OIT) develops and delivers advanced energy efficiency, renewable energy and pollution prevention technologies for application in the U.S. industrial sector. OIT partners with industry and government, and non-governmental organizations, with the goal of significantly improving the resource efficiency and competitiveness of materials and process industries.

The OIT strategy for achieving its goal is embodied in its initiative "Industries of the Future." This is an initiative in which the nine most energy-intensive industries in the United States are working together with the OIT and with government R&D laboratories to find ways to reduce industries' energy use while boosting their bottom line. The initiative is doing this by:

- Creating broad, industry-wide goals for the future
- Identifying specific needs and priorities through industry-led roadmaps
- Forming cooperative alliances to help attain the goals through technology partnerships.

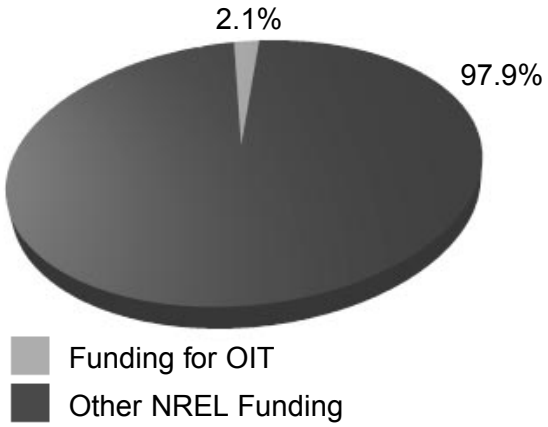


Figure 22. EERE's Office of Idustrial Technologies funded 2.1% of NREL's activities in FY 1999, to develop advanced energy efficiecy and renewable energy technologies for U.S. industry.

Each of these industries has crafted a vision of where they want to go in the next century... and how they'll get there.

NREL's Chemistry for Bioenergy Systems supports the goals and strategies of the OIT primarily through its support of the Industries of the Future (IOF) initiative in the areas of agriculture, forest products, chemicals, glass, and metals.

NREL is supporting the IOF and the industries in several ways, but especially by developing industrial chemicals derived from renewable biomass sources and by developing analytical methodologies that facilitate bioproduct processes. For example, NREL is developing economically competitive bioproducts so that future limited supplies or high costs for fossil fuels do not unduly hamper industrial production now based upon petrochemical feedstocks. Toward this goal NREL uses its considerable expertise in thermochemical conversion of biomass and experience with a wide range of potential technologies for producing valuable industrial chemicals from renewable source materials. Examples include

- Clean fractionation of biomass into cellulose for the production of ethers and esters that are used to manufacture rayon, acetate fibers, and thermoplastics
- Clean fractionation of by-product corn fiber for conversion into ethylene glycol and polyols, which are used to produce variety of products, including antifreeze, polyester, and personal care items
- Production of environmentally friendly fuel additives and herbicides from biologically derived levulinic acid
- Production of aromatic monomers from discarded thermoset plastics, which can be used for new plastics production

- Mobile, real-time analysis of thermochemical conversion processes, such as black liquor gasification.

Molecular biology, genomics, and bioinfomatics create outstanding opportunities to convert biomass-derived sugars to create chemicals and materials now made from petroleum feedstocks. During the next five years, NREL will continue to apply its expertise in chemical, thermochemical, and biochemical conversion and processing to identify value-added products that can be produced from biomass. NREL will continue to develop the fundamental and applied knowledge necessary to convert carbohydrates, lignin, and other renewable sources to new and existing markets. NREL will expand its emphasis on expertise that supports the development of all bioproducts, including biomass analytical and characterization methodologies, sensors and controls.

During the next five years, NREL expects to:

- Complete development of portable, rapid analysis tools for measuring the chemical and mechanical properties of biomass
- Demonstrate processes for production of new plastics, e.g., polylactic acid, or polyalkanoates, derived from renewable sources
- Complete development of processes for production of value-added chemicals from complex mixtures of sugars
- Demonstrate, with an industrial partner, the production of chemicals using "Green" processing technology

Communications also plays a vital role in OIT's mission. NREL provides a wide range of communications products and services to OIT programs. For the near-term, major communications projects are the development and production of the "Best Practices" Web site, design and maintenance of the OIT Web site, and the production of bimonthly publication of the "flagship" Energy Matters newsletter. NREL will also produce nearly 70 project and case study fact sheets for OIT programs and will continue to research, write, and produce numerous electronic and print products as required by OIT and its various programs and strategies.

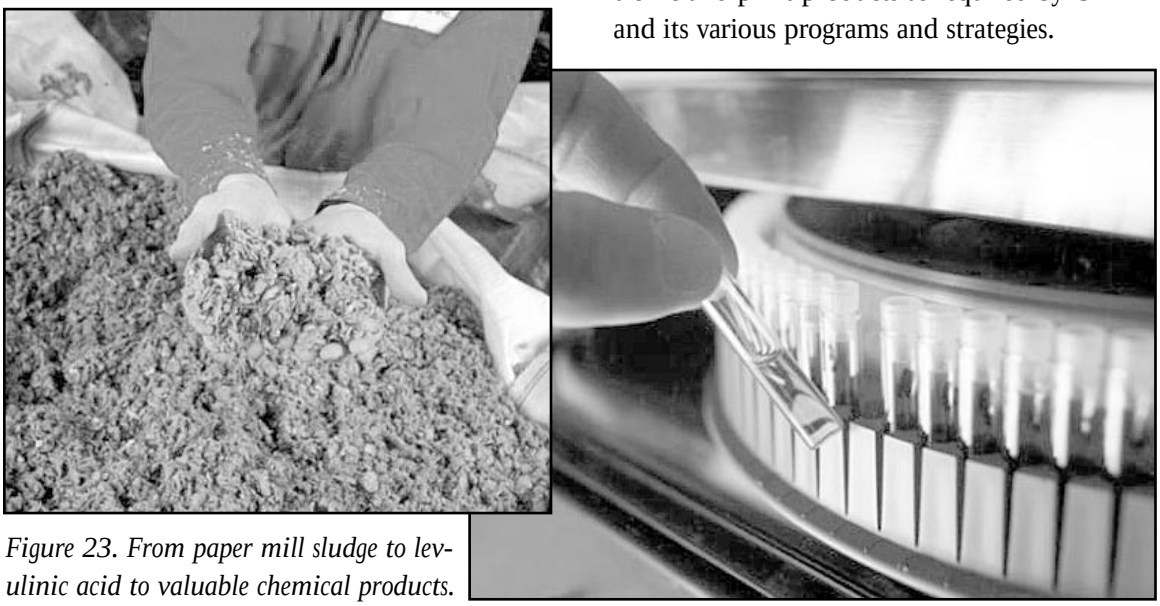


Figure 23. From paper mill sludge to levulinic acid to valuable chemical products. NREL, industry, and other government laboratories are working together to perfect a process that can turn waste from landfills, agricultural industries, and paper mills into products ranging from environmentally-friendly herbicides and pesticides to gasoline additives and petrochemical-based intermediates.

Accomplishments in FEMP

- *In FY 1999 NREL provided assistance to 26 federal renewable energy, energy efficiency, or water conservation project teams, far exceeding its goal of 10.*
- *In the past year, NREL FEMP helped to negotiate nine ESPC and utility service contracts for government agencies, for a total of $76.6 million in private-sector investments; these projects should save $15 million in energy costs annually as well as 15,000 metric tons of carbon equivalent annually*
- *NREL and DOE GO recently helped NASA Johnson Space Center award a delivery order that calls for $20 million of private-sector investments in greater energy efficiency at the Space Center; this should save $2 million per year in energy costs.*
- *NREL helped develop the first FEMP Services Operations Plan, which was issued in February 1999; FEMP Services provides the government with a one-stop service center that helps agencies with technical or financing assistance for energy efficiency and renewable energy projects.*

Federal Energy Management Program

NREL works primarily with DOE FEMP staff and partners at other national laboratories, in other government agencies, and in industry. This work focuses on programs and projects designed to save energy, water, and money at federal facilities. Since the federal government owns or leases more than 500,000 facilities, it has an enormous number of opportunities to use energy more efficiently, install cost-effective renewable energy technologies, and conserve water resources, all of which can help to protect and sustain our environment. Therefore, Executive Order 13123 has directed federal agencies to reduce energy consumption in their facilities from 1985 usage levels by 35% by the year 2010, use more renewable energy, and implement water conservation measures.

DOE FEMP's three major areas of work are technical assistance, project financing, and planning, reporting, and evaluation. One way NREL assists DOE and its project partners is by providing expert technical assistance, such as energy- and water-use audits or training in the use of renewable energy systems, for federal energy and water efficiency projects. NREL has also been directed to take the lead in several national initiatives, including the President's Million Solar Roofs Initiative and the National Park Service Green Parks Initiative, which is managed by DOE and the U.S. Department of the Interior.

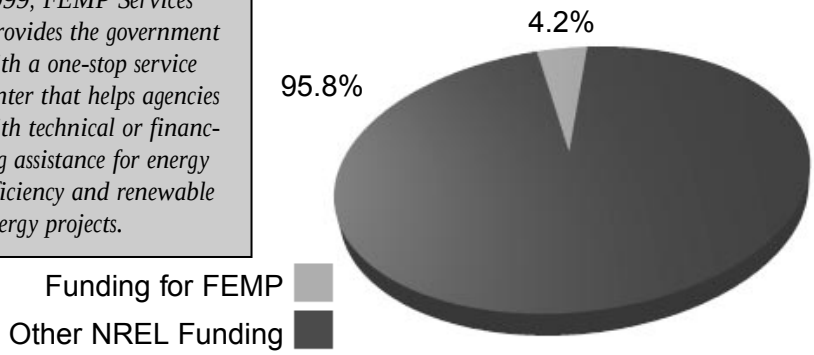


Figure 24. EERE's Federal Energy Management Program provide NREL with 4.2% of its funds in FY 1999 to support activities to help federal facilities save energy, water, and money through the use of energy efficiency and renewable energy.

In addition, NREL provides a great deal of assistance to agencies in the use of project financing. NREL has worked closely with DOE Headquarters, the regional offices, the Golden Field Office (GO), and other laboratories to establish a streamlined reimbursable process for federal agencies to pay for FEMP services. Although this process was originally set up for the regional and technology-specific Super Energy Savings Performance Contracts (ESPCs), it is now being expanded to include all FEMP services. The Super ESPCs are streamlined contracting vehicles that federal agencies can use to obtain private financing for projects that will increase their energy efficiency and provide them with cost-effective renewable energy systems. NREL has the technical lead in four of the six Regional Super ESPCs and serves the function of business manager for much of the overall Super ESPC efforts. NREL has also supported FEMP's Utility Program in a number of ways, including assisting with utility service contracts, facilitating green power procurements, and addressing the implications of utility restructuring.

NREL also provides comprehensive training to Federal employees who want to either implement energy efficiency and renewable energy in their facilities or make use of an ESPC or a utility service contract. NREL staff assist in producing training and educational materials and in maintaining several informative Web sites, including the DOE FEMP Web site on the Energy Efficiency and Renewable Energy Network.

Over the next five years, NREL expects to continue to provide extensive technical assistance to energy managers, procurement officers, and

project leaders in the federal government, as well as a significant amount of assistance to agencies using reimbursable FEMP services. The team also intends to support the organizational changes currently planned by new leadership in DOE FEMP and to continue to respond to FEMP's needs throughout the Department and its laboratories.

Office of Planning and Budget Management

NREL conducts analyses and provides the primary information outreach mechanisms for DOE through EERE's Office of Planning and Budget Management.

Energy Analysis

The DOE, NREL, and others have growing analytic needs that demand high-quality and credible analysis using state-of-the-art tools for a variety of purposes, including:

- Clean energy program planning
- Understanding energy markets and clean energy applications
- Identifying the most effective approaches to energy R&D
- Guiding and optimizing the benefits of deployment facilitation activities
- Projecting the future contributions and benefits of clean energy technologies
- Evaluating the impact of federal environmental air emissions regulation's on the competitiveness of renewable technologies
- Supporting the formulation of sound clean-energy policies

NREL's strategy for serving these growing analytic needs is to develop a Clean Energy Analysis capability that draws upon and applies the best analytic talents worldwide to address the various key issues facing DOE's clean energy programs. The overall capability will include use of in-house expertise as well

Accomplishments and Emphases in Energy Analysis

- *The development of technology characterization for renewable energy technologies.*
- *Analysis and technical support for green markets*
- *Analysis of the role of renewables in addressing issues involving climate change and air quality*
- *Analysis of the impacts of changing energy markets on renewables, especially in the utility sector, which is undergoing substantial restructuring, and in the transportation sector, which is facing ever increasing energy demand for personal mobility*
- *The development of sound projections of the future energy contributions and ancillary benefits likely to result from energy efficiency and renewable energy programs.*

Figure 25. A good example of a federal facility using renewable energy to save energy and protect the environment is this 6.84 kW PV system installed at the Farallon National Wildlife Refuge in California. The PV system, which replaced a diesel generator, has reduced hazardous ship-to-shore fuel transfers, cut fuel use by 4,400 gallons annuyally, and resulted in annual O&M savings of up to $82,000

Technical Information accomplishments

- *Created an EERE Web site to broadcast EERE goals, activities and initiatives*
- *Developed OPT success stories, a printed series of fact sheets on OPT's accomplishments over the last 20 years*
- *Created, published, and distributed more than 1 million copies of the BTS "Energy Savers" booklet*
- *Developed communication strategies for several NREL R&D centers*
- *Implemented EERE's Clean Energy Campaign*
- *Developed the Energy Smart Schools program and Web site*
- *Performed and delivered a Web site benchmarking study for OIT*
- *Developed award-winning Web site for NREL's NCPV and DOE's PV Program*
- *Developed brochure and exhibit on Physics at NREL for the Centennial conference of the American Physical Society*
- *Developed and distributed "Choices for a Brighter Future" for OPT, a printed document that provides regional perspectives for developing renewable energy.*

as expansion of that in targeted areas of importance to EERE's technologies and programs. The strategy also calls for establishing collaborations with several renowned analytic groups in universities and private institutions to enable ready access to their individual capabilities and expertise as those become relevant for specific analytic issues. NREL will serve as the manager and integrator of this overall collaborative analysis program. NREL is also developing an Internet platform to enhance the execution and communication of energy analysis using current databases, the best available tools, transparent methodologies, and ready dissemination and discussion of results. The overall goal of this strategy is to develop and provide the nation with an energy analysis center of excellence comparable to our several national technology centers, such as the NWTC and the NCPV.

Technical Information and Information Services

NREL maintains and updates the Energy Efficiency and Renewable Energy Network (EREN), which is the official Web site for EERE. Initially developed by NREL in cooperation with Oak Ridge National Laboratory and Argonne National Laboratory in 1994, EREN is a repository of EERE information from all EERE sector and program sites.

NREL redesigns the site in response to customer and user needs, adds new content, and performs maintenance. In FY 1999, NREL worked with Sandia National Laboratories to develop an online user survey and to conduct two focus groups on EREN. The feedback and suggestions from these efforts are presently being incorporated into the EREN site. In the future, NREL will increase its customer survey techniques to even better discern audience focus and needs; these results will help EERE and NREL to reshape Web site content most effectively.

NREL also oversees the operation of the Energy Efficiency and Renewable Energy Clearinghouse (EREC), which provides information in response to more than 60,000 public requests per year (actually handling 73,000 requests in 1999) about energy efficiency and renewable energy via phone, fax, mail, and email. In contrast to EREN, EREC provides customized assistance, being careful not to endorse specific brands or products. For example, EREC helps requestors find efficient appliances, choose good windows, use alternate forms of energy such as solar and wind, and design buildings that take less energy to operate. In the future, NREL will continue to provide the means to answer these inquiries, monitor customer satisfaction with this service, and provide new and updated information.

NREL works with EERE to prepare many different types of technical communications to enhance the awareness of EERE's technical accomplishments, including print publications, electronic documents, Web sites, trade media outreach, and CD ROMs. NREL also combines its knowledge of EERE technologies and stakeholders to assist EERE in analyzing information needs and planning communications strategies to reach particular audiences with technical information. NREL expects to continue assisting EERE with its technical information needs in the future in similar ways.

Office of Science

The Department of Energy is the third largest government sponsor of basic research in the United States, primarily through programs managed by the Office of Science. The research programs sponsored by the Office of Science extend the frontiers of basic scientific knowledge in the physical and biological world and in the nature of matter and energy.

The great majority of the R&D that NREL does for the SC is performed for the Office of Basic Energy Sciences (BES), whose mission is to provide fundamental knowledge in the natural sciences and engineering as a basis for new and improved energy technologies and for understanding and mitigating the environmental impacts of energy use.

NREL supports the BES and SC missions and goals by conducting R&D that emphasizes renewable energy technologies such as photovoltaics and other means of exploiting solar energy. NREL performs its research primarily in three subprogram areas — materials sciences, chemical sciences, and energy biosciences.

Materials Sciences

NREL's cutting-edge research in materials science is aimed at developing new classes of advanced semiconductor alloys and structures and novel renewable energy processes, and to gain a fundamental understanding of the phenomena and properties important to the behavior of materials. Activities include ordering in semiconductor alloy materials, composition modulation in semiconductors, transition-metal oxides, low-band-gap nitrides, and solid-state theory.

Ordering in semiconductor alloys. A fertile research area is the spontaneous ordering that some III-V semiconductors exhibit under certain growth conditions. Of particular interest

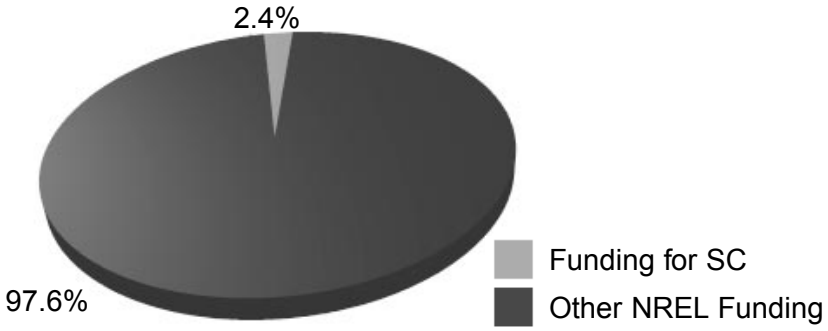


Figure 26 DOE's Office of Science provided NREL with 2.4% of its funds in FY 1999 to support fundamental research activities in materials sciences, chemical sciences, and energy biosciences.

to NREL researchers is the ordering that can occur in $GaInP_2$. Spontaneous ordering can modify the band gap of semiconductors and result in valence band splitting. These, in turn, can affect the electronic and optical properties. NREL researchers are using Raman spectroscopy, ultra-fast time-resolved spectroscopy, spatially resolved photoluminescence and other advanced techniques to investigate spontaneous ordering. This work is leading to the ability to control growth parameters and to adjust material properties to suit specific applications.

Composition modulation. Composition modulation is a phenomenon whereby, under certain

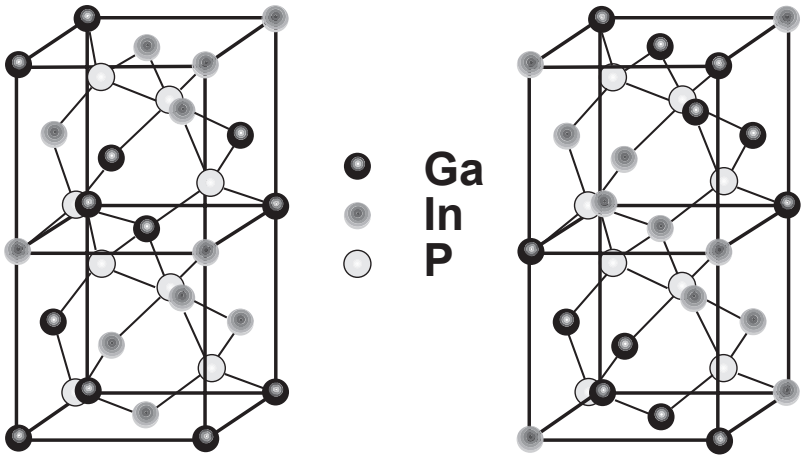


Figure 27. Grown under the right conditions GaInP can exhibit CuPt ordering (where Ga and In align themselves along alternative planes [right], instead of being randomly oriented [left]), which leads to significant changes in alloy physical properties. Thus, by controlling growth parameters, NREL scientists can adjust the physical properties of the alloy.

growth conditions and with certain III-V semiconductor alloys, charge carriers can be quantum mechanically confined to narrow lateral strips on a cell. The result is that electrons and holes can be physically separated from each other, leading to large reduction in recombination and hence a large increase in collected photocurrent. NREL researchers use a variety of spectroscopic techniques to study the electronic properties of composition-modulated materials, what influences the formation of composition modulation, and how to control its orientation.

Transition-metal oxides. Due to their high operating potential and their large capacity, transition-metals such as $LiCoO_2$ and V_2O_5 make excellent cathodes in Li-ion batteries. However, questions persist regarding the interrelationship of the electronic, structural and battery properties, particularly with respect to the loss of capacity with repeated voltage cycling. We are growing high-quality films of both $LiCoO_2$ and V_2O_5 on a variety of substrates, and using Raman scattering to study the Li diffusion rates during charge and discharge over a wide range of Li concentrations.

Low-band-gap nitrides. Low-band-gap nitrides can be used to lower the band gap of ternary III-V alloy semiconductors. This could lead to the fabrication of PV devices with 3, 4, and more junctions, to efficiently capture and convert to electricity a larger percentage of the solar spectrum. NREL researchers are currently synthesizing alloys using nitrides and applying them to multijunction cells, and are modeling the effect of nitride substitution on deep levels and atomic relaxation.

Solid-state theory. NREL's solid-state theory group investigates the theoretical foundations of photovoltaic materials, quantum nanostructures, and order-disorder phenomena in semiconductor and other materials. For photovoltaic materials, NREL theorists use first-principles electronic structure theory to explain material properties and electronic structure of chalcopyrite materials, and to explain why some III-V semiconductors exhibit spontaneous long-range order under some growth conditions, whereas others undergo short-range phase transitions between order and disorder under other growth conditions. For nanostructures, the scientists use a variety of theoretical methods to calculate electronic, optical-transport, and structural properties of semiconductor quantum dots. They develop theoretical methods for predicting structure and properties for advanced Li-ion battery materials. And they develop new methods with which they can quickly search for, and predict likely properties of novel semiconductor materials. Recently, the group developed a new method — inverse band structure — to predict the atomic configuration and crystal arrangement of a chemical system with a prescribed band gap. This could open the way to 'quantum engineering' of materials with desired electronic properties.

Chemical Sciences

Researchers in the chemical sciences are developing the basic science that will form the foundation for advanced technologies that will produce liquid and gaseous fuels, high-value chemicals, and electricity from sunlight, water, carbon dioxide, and other simple substances using photoactive semiconductors or molecular systems. Our investigations involve such research areas as photochemical solar cells, carrier dynamics at semiconductor-liquid interfaces, synthesis and characterization of quantum dots, interfacial photochemistry, molecular semiconductors, and basic research in synthesis and catalysis.

Photochemical solar cells. The photochemical solar cell is a potentially low-cost, efficient solar cell based on dye-sensitized nanocrystalline films of titanium dioxide. This device contains a photelectrode made of a nanocrys-

talline film of titanium dioxide (TiO_2) particles. Molecules of a ruthenium-based dye are adsorbed onto the surface of the TiO_2 particles so that, when exposed to light, they inject electrons into the semiconductor material, which are collected as current. After traversing the external circuit, electrons are injected back into the cell and become part of a series of reactions that restore the oxidized dye molecules to their original state to start the process over. The research focuses on understanding the basic mechanisms involved and solving problems that limit efficiency. Excellent progress has been made. We are gaining an understanding of the potential distribution in the nanocrystalline TiO_2 film, the pH-dependence of the cell characteristics, the charge transport through the TiO_2 electrode, and the kinetics of electron injection from the photoexcited dye into the semiconductor.

Carrier dynamics and quantization effects at semiconductor-liquid interfaces. Photoelectrochemistry, photocatalysis, and photoelectrochemical energy conversion are based on phenomena at semiconductor-liquid interfaces. Upon photoexcitation, electron-hole pairs created by absorption of light are separated at these interfaces and subsequently drive electrochemical oxidation-reduction reactions at the semiconductor surface. Systems based on these reactions can be used to produce electricity, fuels, or chemicals. It is extremely important to understand the mechanisms and rates of electron-hole creation, electron transfer, and electron-hole recombination. Gaining an understanding here will lead to higher efficiencies and lower costs for systems based on these reactions. NREL scientists are gaining insight to the electron-transfer mechanisms through the use of simulation modeling and photoluminescence measurements.

Synthesis and characterization of quantum dots. Semiconductor quantum dots have dimensions typically in the range from 2 to 25 nanometers, representing a new class of materials between molecules and solid-state forms. They are large enough to maintain crystal structure and small enough to produce discrete electronic energy levels. These characteristics make them extremely promising for use in highly efficient photoconversion systems. NREL researchers have succeeded in synthesizing quantum dots of a variety of III-V semiconductor materials, including InP, GaAs, GaP,

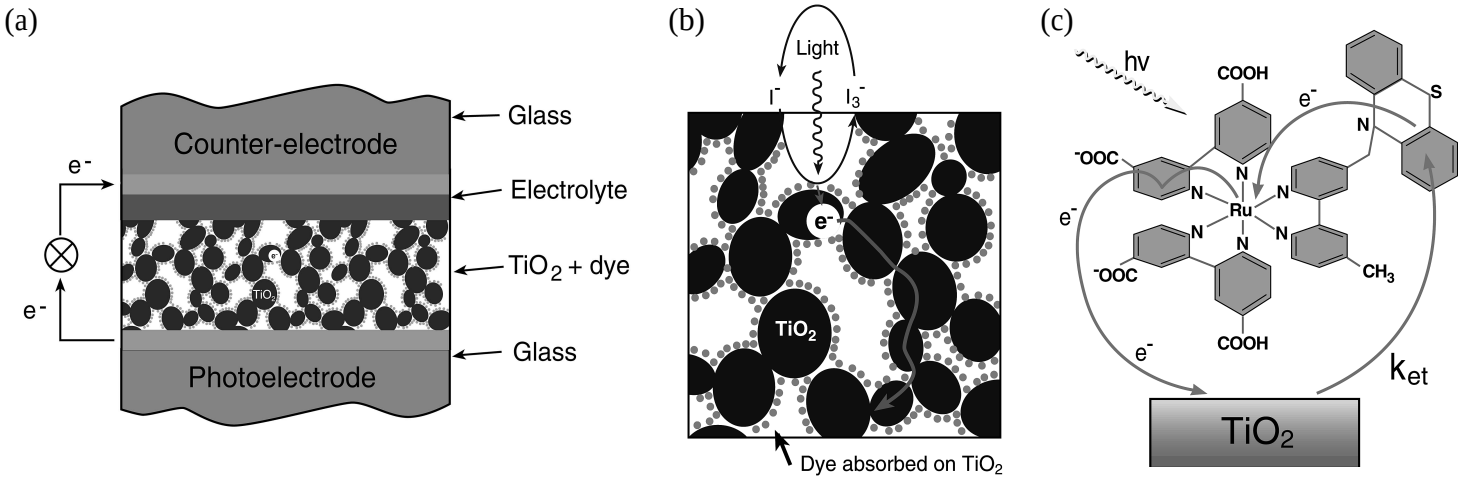


Figure 28. NREL scientists helpd pioneer the concept of the photoelectrochemical solar cell (a), whcih uses a photoelectrode comprised of nanocrystals of TiO_2 coated with a ruthenium-based dye (b). The TiO_2 abosrbs UV solar radiation and converts it to electric current. Ruthenium dye (c) greatly extends range of the spectrum absorbed and converted by the cell.

GaN, and GaInP, and are studying their fundamental optical and electrical properties.

Interfacial photochemistry. We have observed that chemically modifying the TiO_2 of photochemical solar cells, specifically with dye-sensitized nanocrystalline semiconductor electrodes, causes an improvement in performance and an increase in photovoltage. Our objective is to understand how this happens, by studying the dynamics and kinetics of charge transport and recombination across the solid-state/electrolyte interface and by investigating the effect of the nanoporous structure on the transport of redox species in solution. We are gaining insights by applying a new technique — modulated photovoltage spectroscopy — and by developing theoretical models that enable us to derive analytical expressions for the photovoltage.

Molecular semiconductors. We are studying the photophysical, photoelectrical, and photoelectrochemical aspects of organic semiconductors, with a special emphasis on exciton dynamics. Charge carriers in organic semiconductors are usually not created directly by light absorption but rather by dissociation of the initially created exciton. This is one of the major differences between inorganic and organic semiconductors, and it is one of the major similarities between organic semiconductors and natural photosynthetic systems. Consequently, the study of organic semiconductors provides a conceptual bridge between these two important types of photoconversion systems. Our studies have produced two important recent results. First, we have developed a thin-film technique that promises to overcome the problem of slow charge transfer in molecular semiconductors. Second, we have successfully synthesized liquid crystals based on organic perylene diimide, which may have important future applications in organic solar cells.

Photocatalysis and Electrocatalysis. Research in this area addresses a number of scientific problems in the recovery and utilization of CO_2. The ultimate objective is to provide a route in addition to biomass for the renewable production of carbon-based fuels (such as methane, methanol, and ethanol) from CO_2. Recovering CO_2 from flue stacks or the atmosphere will require new efficient methods for CO_2 separation and concentration. For this process, NREL is investigating new methods based on electrochemically switchable molecules. In addition, we are developing new homogeneous electrocatalysts for reducing CO_2 to fuels. These studies involve the synthesis of new catalysts, detailed spectroscopic and structural characterization of these catalysts, and investigation of the mechanisms of the catalytic processes. Of particular interest are general mechanistic features of these catalysts and a detailed understanding of the thermodynamics of M-H and M-C bonds that are involved in fundamental catalytic steps such as C-H, C-C, and C-O bond formation and cleavage. We are also using new rapid-throughput and combinatorial techniques to enhance the rate of catalyst discovery and optimization. These studies involve a number of collaborations with other national laboratories and with universities.

Energy Biosciences

The goal of NREL's research in the energy biosciences is to advance basic understanding of bacterial and plant photosynthesis, including relevant metabolic pathways, and to apply that knowledge to develop renewable fuels, chemicals, and materials as well as address environmental problems. For the BES, NREL's current focus is on fundamental photosynthesis research.

Photosynthesis Research. Plant photosynthesis produces the oxygen we breathe, the food we eat, and important materials for our hous-

es, clothes, and industries. In one way or another, virtually all the energy we use comes from the process of photosynthesis. Indeed in the future, photosynthesis will continue to provide plant and algal biomass for our fuel and chemical needs through indirect biomass conversion processes (including fermentation to alcohol and gasification to biocrude) and direct “photoconversion’ processes. Through photoconversion, where the organism itself directly produces the desired end product (such as hydrogen, biodiesel, and specialty chemicals) using light-driven biological processes, these products will be renewable and non-polluting, and their production won't contribute to global change problems.

NREL researchers are investigating detailed mechanisms of those photosynthetic processes that provide the energy that reductant plants require to fix carbon and grow. In particular, NREL research focuses on the structure and function of photosystem II (PSII), one of the two light reactions of algal and green plant photosynthesis. PSII concentrates sunlight by first absorbing the energy within membrane-bound, pigment-protein complexes called light-harvesting antennae and then transferring that energy to a specialized pigment-protein complex called the PSII reaction center in an excitation energy transfer process. The reaction center acts like a miniature solar cell and uses the energy to pump electrons across the photosynthetic membrane in a charge-separation process. This separated charge provides the chemical potential that drives subsequent plant metabolism. NREL researchers have succeeded in measuring this extremely fast charge-separation reaction, which occurs in a few trillionths of a second. They have also succeeded in imaging that part of the membrane/protein structure that performs these basic photochemical processes.

Another area of NREL interest examines the water-splitting process of photosynthesis that is directly coupled to charge separation in the PSII reaction center. Water is the source of reductant that plants use to fix atmospheric carbon dioxide; it is also the substrate that algae mobilize to evolve hydrogen. NREL's main interest has been in determining the structure of the catalytic site of water oxidation, which facilitates a concerted multi-step reaction associated with the absolute requirement for a tetrameric Mn cluster. NREL has identified two proteins, constituting most of the PSII reaction center complex, that bind the cluster and has made significant progress in identifying individual amino acid residues on these proteins that provide specific ligands to Mn.

This knowledge will prove useful in developing a potentially commercial algal hydrogen-producing process. It will also be valuable for addressing plant sequestration of excess atmospheric carbon dioxide to counteract global change problems, and for designing future generations of artificial photoconversion devices that produce renewable energy by mimicking natural photosynthetic processes.

Operations & Infrastructure

The Solar Energy Research Facility, Part of the R&D Campus at DOE's South Table Mountain site, is a state-of-the-art laboratory building that houses offices and R&D facilities for photovoltaics and basic sciences.

Human Resources

Part of NREL's mission is to remain the world's recognized leader in R&D in the renewable energy and energy efficiency technologies. Perhaps the most critical element in attaining and retaining this level of excellence is embodied in the quality of staff employed at the Laboratory. Consequently, one of our highest priorities is to recruit, retain, and develop the highest quality staff possible. Toward this end in FY 1999, we conducted a study on competitive benefits and salaries for all positions at NREL. This study resulted in adjustments for a large percentage of NREL's 828 staff members, ensuring that they received compensation commensurate with others in their field with similar qualifications at similar institutions in the government and private sectors. This effort will be an ongoing one at NREL — we will continue to conduct surveys to compare benefits and compensation packages with other organizations. But this continuing survey and adjustment is just one of the ways in which HR will attract, retain, and develop its workforce. Other ways include:

- Defining the leadership role of directors, managers, and team leaders; NREL will develop a set of competencies common to all leadership positions, emphasizing the leader's role as coach, mentor, and employee developer
- Developing a career track for leaders and technical experts, to offer an alternative to a management track and to encourage staff to grow in their technical role
- Providing employees with challenging work assignments

Table 1. Education Level of Laboratory Staff

	No Degree	Associate	BS/BA	MS/MA	PhD	Total
Administrative	21	1	40	25	7	94
Clerical	88	4	17	1		110
Communications	3	1	25	12		41
Computer Science	21	6	18	7		52
Engineers	11	3	41	39	30	124
ES&H	1	1	4	1		7
Group managers	6	1	6	6		19
Operatives	3	1				4
Program Managers			5	8	6	19
Project Leaders	1		11	18	10	40
Protective Force	5	1	1			7
Research Participants				2	33	35
Scientists	11	2	28	30	82	153
Senior Managers — ADM	1		4	3		8
Senior Managers — R&D			1	5	7	13
Skilled Craft Workers	13	3	7	1		24
Technicians	29	7	15	1		52
Unskilled Laborers	7					7
Total	**221**	**31**	**223**	**159**	**175**	**809**

- Providing employees with rewards and recognition, in which NREL will work diligently to gain national and international awards, honors, and prizes for the Laboratory's outstanding research efforts and accomplishments
- Offering flexible work schedules and arrangements, with a particular emphasis on defining and implementing an appropriate sabbatical program
- Becoming a learning organization through diversity

As part of our five-year plan for bringing NREL to the next level of excellence, the Laboratory considers a proactive diversity program to be critical to its success in leading the renewable energy community into the next millennium. In our commitment to become a diversity leader, we have developed a diversity program that will promote intellectual and management excellence by recruiting, developing, training, and retaining a qualified, diverse workforce to meet our customer's needs.

The diversity program is an on-going effort whose success will be measured by long-term commitment and results. Overall, NREL has a strong diversity program and has maintained consistent levels in terms of gender and ethnicity. Lately, however, the Laboratory has increased its representation of females at top-level management positions. In addition, more than 41% of managers in the administrative services directorate are females, and the Laboratory has

Table 2. Diversity of Laboratory Staff

	Asian		Black		Caucasian		Hispanic		Native American		Total	
	M	F	M	F	M	F	M	F	M	F	M	F
Administrative	1	2	3	1	26	54	2	2	1	2	33	61
Clerical		1	3	4	10	76	2	12		2	15	95
Communications					11	29		1			11	30
Computer Science	4	1			27	17		1	1	1	32	20
Engineers	11				91	20	1			1	103	21
ES&H					4	3					4	3
Group managers	1		2		8	8					11	8
Operatives			2		2						4	
Program Managers					17	2					17	2
Project Leaders	1	2		2	22	12		1			23	17
Protective Force					4	2	1			1	5	2
Research Participants	7	3			21	3					28	7
Scientists	14	5		1	108	19	5	1			127	26
Senior Managers — ADM					6	2					6	2
Senior Managers — R&D	1	1			9	2					10	3
Skilled Craft Workers	1		2		17	2	2				22	2
Technicians			1		33	15	1	1	1		36	16
Unskilled Laborers			1		5		1				7	
Total	**41**	**15**	**14**	**8**	**421**	**266**	**15**	**19**	**3**	**7**	**494**	**315**

increased its representation in the Native American, Asian, African American, and Hispanic categories. In the near future, NREL plans to strengthen its diversity program by:

- Designing a campaign to more proactively advertise for underrepresented populations, especially those in science and engineering
- Strengthening NREL's relationships with schools and communities by targeting college-recruiting programs to identify, attract, and hire outstanding candidates, with a special emphasis on recruiting qualified people from underrepresented populations
- Appointing an NREL volunteer group to work with stakeholder organizations within the community to organize celebrations of diversity events such as Black History month, Women's History month, Disabilities Awareness month, and more

Safeguards and Security

NREL's Safeguards and Security program is designed to employ a risk-based approach for providing cost-effective protection for personnel and property. Because NREL does not have classified information or nuclear material there are no individuals at NREL who hold an NREL-sponsored security clearance.

NREL conducts the Safeguards and Security program in compliance with applicable sections of DOE Order 470.1. DOE Security has recently undergone intense scrutiny for appropriate and effective programs. NREL fully participated in a DOE headquarters mandated Security Employee Awareness training in August 1999. While NREL is exempt from the DOE Order on Foreign National Visits and Assignments, NREL does maintain a policy and a program to address pertinent issues regarding foreign nationals.

During the next five years, we expect the level of security at NREL to remain consistent. However, under orders from DOE headquarters, we are planning to convert the Safeguards and Security budget from indirect overhead funding to a direct-funded program in FY 2001. In addition, we will be issuing new photo identification badges to all NREL staff within the next two years. And we recently installed a new security system at the Site Entrance Building, which will enhance our capabilities to control and monitor access to the site, monitor emergency and security alarms, and conduct electronic surveillance of all NREL sites. We anticipate our next regularly scheduled Safeguards and Security Inspection to be held in 2001.

Site and Facilities Management

Existing Conditions

NREL operates in five separate locations near Golden, Colorado, 10 miles west of Denver: the DOE-owned South Table Mountain (STM) and National Wind Technology Center (NWTC) sites as well as leased facilities in the Denver West Office Park (DWOP), the Joyce Street Facility (a warehouse), and the 48th Street Facility (a small warehouse-type facility used for some building energy research.) In total NREL occupies 630,000 gross square feet (ft^2) of DOE-owned or leased space (all sizes are given as ft^2). Of this total, about 40% is leased. Table 3, Laboratory Space Distribution, summarizes the land area and occupied space information on each site.

South Table Mountain Site. The STM site (Figure 29), with 136 acres of developable land, is located on the toe, side, and top of a mesa. Because of the topography of this site, 175 acres were recently placed into a conservation easement adjacent to other open space owned by Jefferson County in exchange for 25 acres of developable land south of the STM site (included in the 136 developable acres). An additional 16 acres of the site are consumed by access and utility easements.

The STM site is in a growth area that is experiencing substantial commercial and residential construction as well as rising costs and rents. The STM site is visible to the surrounding com-

Table 3. Laboratory Space Distribution.

Location	Land Area (acres)	% of Total	Occupied Space (ft²)	% of total	Total Staff
STM	327*	53	320,000	51	392
NWTC	280	45	50,000	8	100
Leased Off Site	11	2	260,000	41	533
Total	**618**	**100.0**	**630,000****	**100.0**	**1025**

**Approximately 191 acres are restricted via a conservation easement.*

***Includes space tracked in FIMS database (incl. bldgs and trailers) as well as property not tracked in FIMS (e.g., small bldgs and leased bldgs.)*

munity for several miles; consequently, NREL is sensitive to the concerns of residential neighbors about minimizing the visual, noise, and other impacts of research and construction activities.

The STM site is only partially developed. It houses about 400 people and the majority of NREL's R&D activities in two major buildings and several smaller research buildings. These R&D activities include low-bay and high-bay laboratories, process development and pilot-scale facilities, and research support spaces for R&D related to chemistry, biology, physics, thermal sciences and engineering, vehicle engineering, outdoor and field testing, and interdisciplinary activities. The STM site supports all program areas except wind energy research, as well as NREL's shipping and receiving and maintenance activities.

Future uses of the South Table Mountain Site will focus on low-bay and high-bay laboratories, some low-impact testing and process research, and research support facilities. It will continue to be NREL's principal site for its core research programs.

Solar Energy Research Facility. Built in 1993, this 116,000-ft² laboratory is an energy-efficient showcase that has won numerous architectural design awards. Using 36% less energy than the federal standard for such buildings, it is a model for innovative energy-savings features such as daylighting, high-efficiency lighting, photovoltaic-controlled window shades, direct and indirect evaporative cooling, exhaust heat recovery, high-efficiency motors, an oversized cooling tower, and a trombe wall. This laboratory houses researchers and low-bay labs that support photovoltaics, superconductivity, materials science, surface science, physics, and related research. Designed to accommodate 160 people, this facility currently houses 225; additional related research work that would benefit from being located in this building is being conducted in other facilities because of the overcrowding.

Field Test Laboratory Building. Built in 1984, this 96,000-ft² laboratory has always been a multi-purpose research building, frequently reconfigured to meet changing R&D needs and programs. It contains both low-bay laboratories and high-bay research spaces. The latest modifications, completed in FY 1999, reconfigured

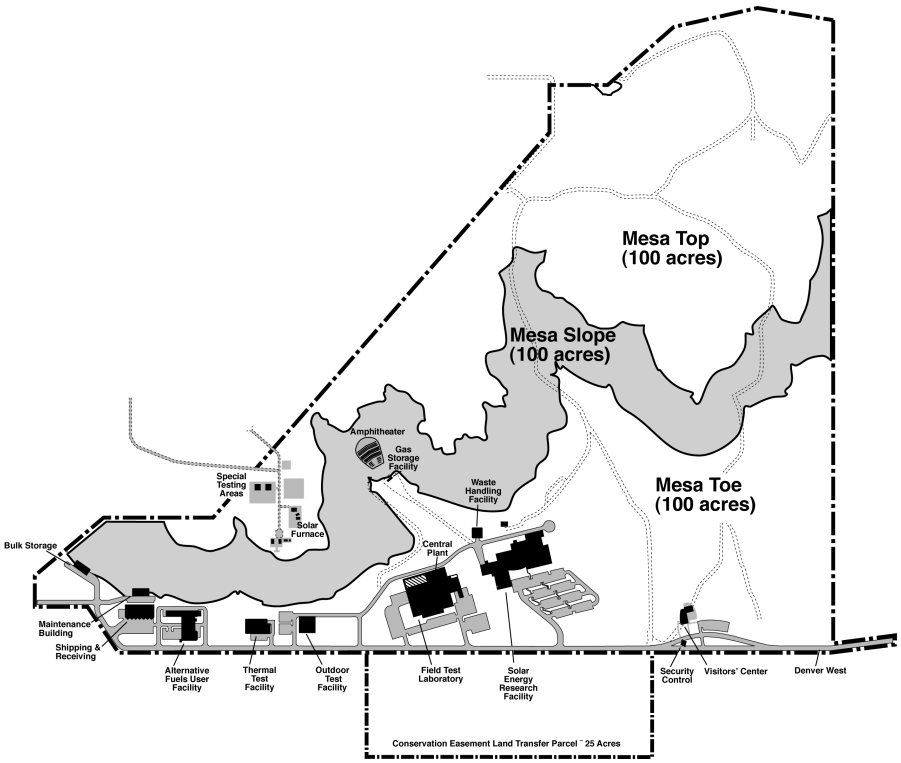


Figure 29. South Table Mountain Site

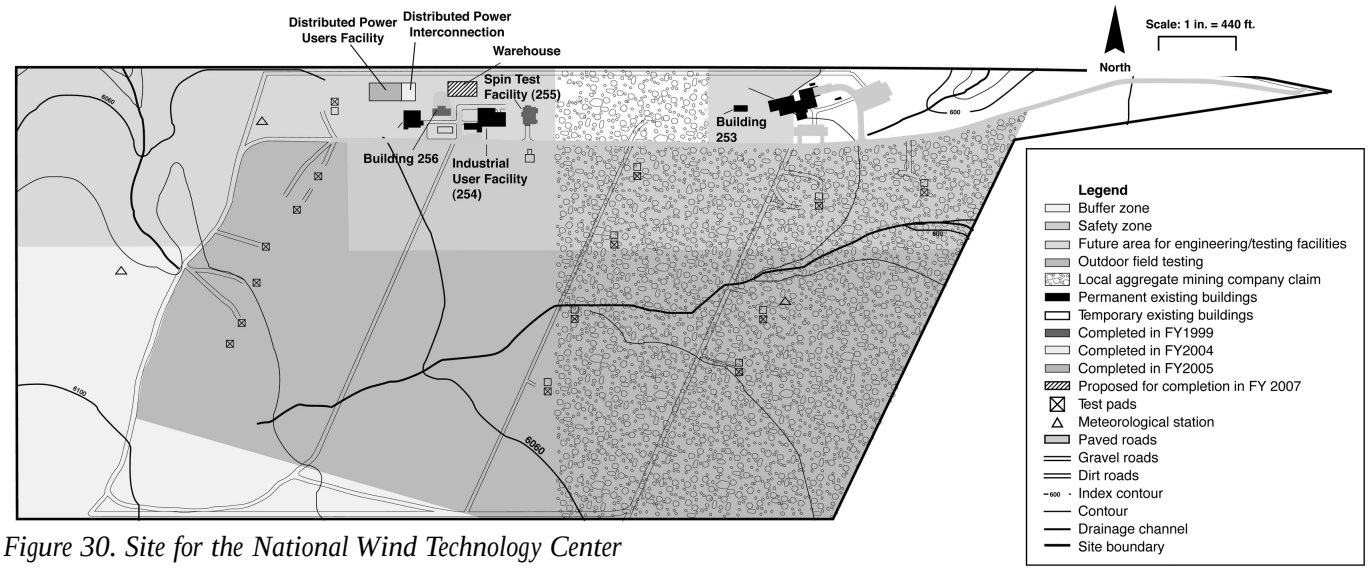


Figure 30. Site for the National Wind Technology Center

29,000 ft^2 of interior space to laboratories and research support space. This reconfiguration allowed NREL to move some laboratories and researchers from leased space in the Denver West Office Park to the Field Test Laboratory Building. These reconfigurations are not complete, however; plans are to upgrade and reconfigure more interior space to maximize research space within the current footprint and add office space as one solution to overcrowding in other facilities and high lease costs. The research space within the facility suffers from aged building systems, cracked flooring, rundown exterior surfaces, and other problems.

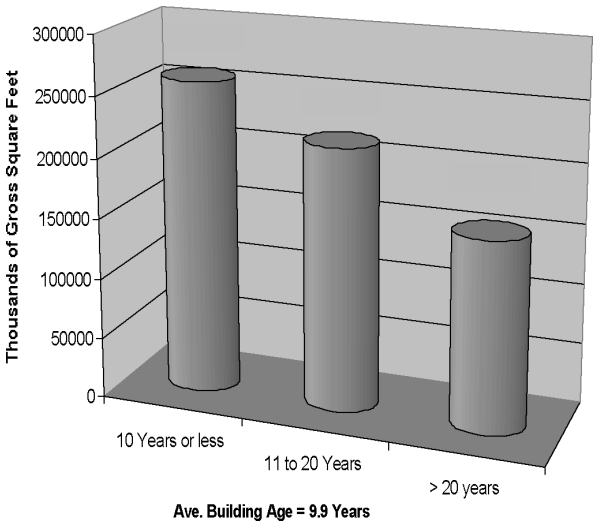


Figure 31. Age of NREL laboratory buildings.

Denver West Office Park. NREL has leased space in this office park since 1977 to house administrative functions and laboratory and non-laboratory research, currently comprising about 500 NREL persons in 190,000 ft^2 in four different buildings. In addition, NREL provides about 20,000 ft^2 of space in these leased facilities for about 100 persons with the DOE Golden Field Office and the DOE Denver Regional Support Office.

National Wind Technology Center. This 280-acre site (Figure 30) is adjacent to DOE's Rocky Flats Environmental Technology Site about 20 miles north of Golden, Colorado. The NWTC site has been only partially developed for research and testing of wind turbines, including extensive outdoor testing, and houses about 100 staff in several small buildings and trailers. While the land is basically flat and accessible, there are currently no water, gas, or sewer services. Further infrastructure investments will be needed to support evolving program activities. Some space has become available in the main building, Building 251, and renovation is needed to allow researchers currently in trailers to move into this space and realize cost savings.

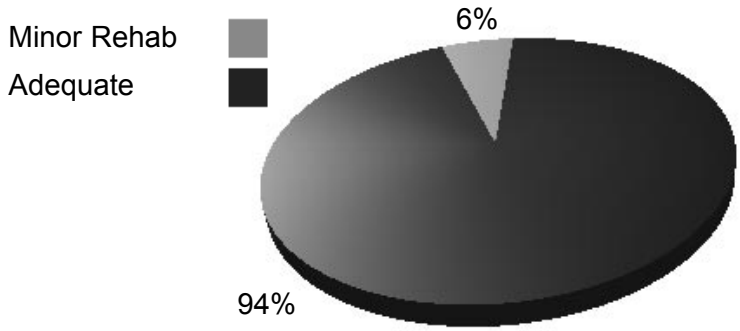


Figure 32. Condition of laboratory space

Other near-term needs at the NWTC include additional wind energy research facilities such as an expansion of the structural blade testing facility, a small wind tunnel, and a larger dynamometer test facility. Future uses of the NWTC will include additional field and outdoor testing for a variety of programs, including distributed and hybrid power systems. Future needs could also include expansion or addition of research support space.

NREL is working with DOE to monitor future developments being planned for the adjacent Rocky Flats Environmental Technology Site, in particular the current proposals for a National Environmental Research Park, which would be quite compatible with NREL's intentions to expand the testing of clean energy systems in this area. Portions of Rocky Flats land could be used for additional systems and field testing in several program areas

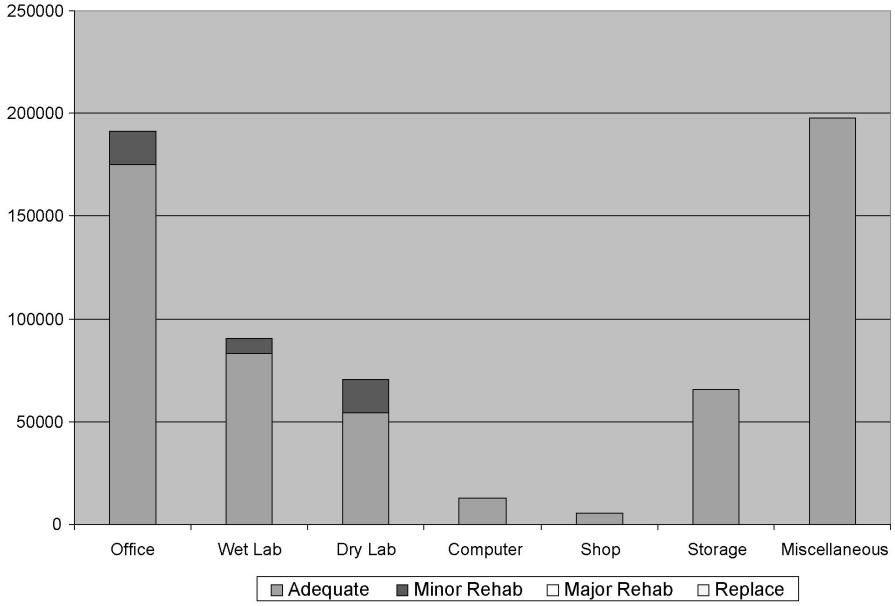


Figure 33. Use and condition of existing laboratory space.

Maintenance and Development of Critical Infrastructure. NREL opened in 1977. As shown in Figure 31, 75% of NREL's buildings are less than 20 years old; virtually all of the buildings older than 20 years are leased facilities. Because of the Laboratory's renewable energy and energy efficiency mission, its sites have no chemical or radiological legacy. As shown in Figures 32 and 33, the great majority of NREL's facilities are in "adequate condition," defined according to categories used in the DOE Facilities Information Management System as having required total repair costs less than 10% of the replacement plant value at any given time.

The total replacement value of NREL's assets (currently still in service) is about $185 million. NREL's buildings and infrastructure (utilities, roads) require some maintenance at this time, and as they age, they will need even more maintenance. In addition, much of the DOE land for NREL is undeveloped or inadequately developed, requiring regular investment. Lastly, 20% (based on acquisition cost) of NREL's capital equipment, both general purpose and program capital, continues in use beyond its expected useful life. Looked at another way, about $22 million would be needed in FY 2000 to replace this outdated equipment.

NREL's benchmark analysis of the costs of maintaining these capital assets adequately indicates that an investment of more than $4 million/year is necessary in FY 2000 dollars (Table 4) for NREL assets including buildings, infrastructure, and general purpose equipment. This includes funds each year to complete the development of NREL's two sites (utilities, roads, walkways, etc). Historically, however, NREL's

average funding for maintaining, upgrading, and developing critical infrastructure is much less than this, typically less than $2.0 million/year. In addition, program capital equipment requires more than $7.0 million/year simply to maintain what we currently have, not including program expansions or changes; NREL averaged only $3.7 million/year in recent years.

Aging and obsolete scientific instrumentation often breaks down, slowing research progress. This forces NREL to use other laboratories around the country for analyses, increasing travel costs and delaying research progress. As the instrumentation becomes more obsolete, research breakthroughs are missed and results are slowed because the most sensitive, highest quality instrumentation is not available.

Information technology must be replaced even more frequently than scientific instrumentation to remain somewhere near state-of-the-art and compatible with other laboratories and research institutions, because of the rapidly changing technology in information systems.

In addition, the lack of funds to maintain buildings and infrastructure explains the cracked floors, inadequate and aged ventilation systems, ineffectively used space, and leaking roofs that are becoming more prevalent in NREL's buildings.

Issues with dependence on leased space. NREL has built only two major laboratory buildings (defined as about 100,000 ft^2 or greater) since the Laboratory opened in 1977, and has built no research support space except for a shipping and receiving facility. At this time, the Laboratory has no unused space in DOE-owned facilities, and has major overcrowding in some buildings; consequently, NREL must continue to use leased facilities for some of its laboratory research. NREL depends almost totally on leased space for research support activities. About 48% of NREL's staff remains in leased space, including researchers and some laboratories.

Table 4. Value of NREL Assets and Sustaining Investments Required

(dollar amounts are in millions)	Acqisition Cost	Replacement Value	Approximate Annual Investment Required		Ref	Average Annual Investment Last Five Years (96-00)
			Absolute	*% of RV*		
Buildings	$54	$95	$1.7	2%	1,2	
Utilities, Roads	$8	$10	$1.4	14%	3,4	
General Equipment	$7	$8	$1.2	15%	5	
Subtotal NREL Capital	$69	$113	$4.3	4%		$1.8
Program Capital	$57	$72	$7.2	10%	5	$3.7
Total NREL Assets	$126	$185	$11.5	6%		$5.5

Ref 1: Benchmarks III, Research Report #18 from International Facility Management Association, 1997. Page 38, Maintenance Cost for Research Industry (actually being paid by companies surveyed) = $3.53/sf in 1996 $, escalated by 2.5% per year to $3.90 in 2000 dollars, times 380,000 sf owned space = $1.5M. Figure of $1.7M shown is average of actual from survey ($1.5) and lowest of recommended ideal ($1.9) = $1.7M.

*Ref 2: Building Research Board of the National Research Council, 1990; quoted in Benchmarks III, Research Report #18 from International Facility Management Association, 1997, page 39. Ideal maintenance costs recommended as 2%-4% of current replacement value. Replacement value of buildings ($250/sf * 380,000 sf = $95M). The required annual investment ranges from 2% - 4%, representing $1.9M - $3.8M. The figure of $1.7M shown is an average of $1.5M from Reference 1 and the lower figure ($1.9M) from Reference 2.*

Ref 3: NREL asset accounting report, 3/20/00. Acquisition cost for infrastructure categories adjusted by GNP price inflator to FY2000 dollars and summed over all acquisition years = total replacement value for infrastructure. Total replacement value divided by 25-yr lifetime = $0.4M

Ref 4: NREL asset accounting report, 3/20/00. Assume that total site infrastructure value escalated to FY 2000 ($9.8M) represents 1/3 of NREL site development (over both sites). Assume 2/3 more to be developed (=$19.6M) over next 20 years = $1.0M/yr.

Ref 5: NREL asset accounting report, 3/20/00. Acquisition cost for general equipment and lab equipment categories adjusted by GNP price inflator to FY2000 dollars and summed over all acquisition years = total replacement value. Total replacement value divided by 7-yr lifetime = $1.2M (general equipment) or divided by 10-yr lifetime = $7.2M (program capital lab equipment)

Because DOE-owned buildings have been added slowly, and generally as quite small (about 20,000 ft^2 or less), immediately-needed R&D facilities, NREL suffers from a shortage of research space that varies in seriousness depending on funding and staffing levels and program changes. NREL is currently operating at a facilities utilization rate of 96% for office space, and 100% for lab space. Unoccupied office space is scattered throughout our facilities in isolated cubicles. Functional working groups are often located on several wings, floors, or buildings. Due to the high occupancy rate and the fragmentation, it is extremely difficult and expensive to co-locate working groups or to efficiently accommodate students, visiting industry partners, university sabbaticals, or additions or transfer of staff to respond to programmatic changes.

This means that there is no flexibility to move, alter, or expand labs as research needs change. Building 16 in the Denver West Office Park continues to house laboratory research because there is no other space available. The HVAC systems in Building 16 are 16–20 years old and have far exceeded their useful life, limiting the types of lab work that can be accommodated. The building has one small elevator designed for passengers that also has to be used as a service elevator to support the laboratories. Agreement with the landlord to continue using the building for laboratories past the current lease is uncertain because the building is located in an office park adjacent to residential areas.

Construction of DOE-owned buildings to house the functions currently in this office park, both laboratory and non-laboratory, would save DOE/NREL more than $4 million/year in lease costs. The FY 2002 request includes options for moving laboratory research and researchers out of leased space, but not research support personnel. Options for a DOE-owned research support building are being considered, and a tentative project is planned for FY 2003 funding.

Affects of Physical Assets on Quality of Research. NREL's buildings are relatively new and well designed, which helps to attract high-quality staff. However, compared to other research campuses, NREL's campuses lack important features that help to attract and retain top-level scientists. The significant crowding in some areas and the severe lack of space needed to allow movement and flexibility in research needs is a deterrent, however, to the most highly sought research candidates. Also, funding restrictions continually force decisions to eliminate meeting rooms, conference facilities, and internal interaction spaces such as a cafeteria; the library, another natural place for interaction, must be located 1-1/2 miles from most of the researchers. A significant number of obsolete scientific instruments discourage sought-after candidates. There are very few walkways between buildings on the STM site, no walkways on the NWTC site, and no landscaping or shade to encourage pedestrian usage.

Energy Efficiency, Environmental Quality, Sustainability, and Neighbors. NREL has important strengths in these areas, along with a desire, the knowledge, and the opportunity to exemplify the best in the DOE system.

Because of the nature of its research activities in energy, NREL has long had an ongoing program for energy management. NREL employs daylighting, energy efficient lighting, direct digital control, variable speed drives, economizer cycles, selective glazing, occupancy sensors, setback thermostats, and other techniques in the integrated design of its buildings to minimize energy use. NREL is also constantly evaluating new technologies and incorporating them into existing buildings and into new designs, when they are deemed to be beneficial. NREL uses approximately 30% less energy than that required in an equivalent 10CFR435 building (code reference). From FY 1996 through FY 1998, NREL reduced its energy use (gas and electric) by 17% by retrofitting its older buildings with applicable technologies.

NREL has also begun a long-term effort to increase the amount of renewable energy used by the Laboratory at its DOE-owned facilities. It is beginning to do this in two ways: (1) by installing, at suitable locations, its own renewable energy systems (wind turbines, photovoltaic arrays, and other systems) and using the energy generated at the Laboratory; and (2) by purchasing, through the local utility, energy that is produced by utility-owned wind turbines or other renewable sources.

The Laboratory has several small efforts contributing to overall sustainability, such as a small recycling program, the purchase of some "green" power, a small amount of onsite power generation, and newer buildings that meet or exceed the standard of 35% or better energy reduction. NREL has identified other actions that could be taken to make the Laboratory sustainable; many of these affect site plans and building construction. These include higher initial investments in energy-saving features for existing and new buildings that will support program goals, more alternative-fueled vehicles in the NREL fleet, improved water management, and innovative management of vehicle traffic and parking on site.

NREL currently meets or exceeds all environment, safety, and health regulations, orders, and codes. The NWTC site entrance from the westbound direction presents a potential safety issue. The site is accessed from a two-lane state highway with a 55-mph speed limit and significant traffic. The absence of a left turn lane or stop sign or stop light increases the opportunity for traffic hazards to employees waiting to turn into the NWTC site. NREL is requesting funds to correct this problem.

NREL has excellent relationships with its immediate neighbors, as evidenced by positive comments at public meetings, regular open meetings addressed to neighbors, and the utilization of local residents on the NREL Architectural Review Board. NREL is committed in its building designs and site planning to low-impact uses (low visual, environmental, and audible impact) on the STM site, and using the NWTC site for other activities. NREL's intentions to improve further its energy usage, water usage, traffic impacts, materials usage and purchases, and so on will encourage further cooperative projects with the local community, particularly the local governments, utility, and water districts.

Site Operations

Maintenance. Maintenance funding at NREL is at a "status quo" level. Basically, the funding level is increased proportionally to the square footage and equipment levels as they increase. Thus, there are no plans or funds to reduce the current deferred maintenance level. As the buildings and equipment age, the maintenance funding level will need to increase.

Property Management. NREL's process for disposition of excess property is initiated by the custodian of the property when it is determined that the property is no longer required. The custodian transfers the property to property management and, based on the type of property, acquisition cost, and condition code, the property is processed through the disposition categories. These categories provide a method in which excess property is screened by NREL, DOE, federal, and state agencies and authorized non-federal recipients, and is sold in a public sale or donated to educational or non-profit organizations.

Facility cost allocation. Space is charged to a tenant based on the amount of space a tenant occupies in proportion to the space occupied by the rest of the tenants. The total Laboratory budget for facilities and associate support overhead is allocated to each tenant based on the tenant's proportion of occupied space. Results on the use of space are mixed. Some tenants

try to reduce their facilities charges to the minimum. However, due to the general shortage of space, and research laboratory space in particular, some tenants "reserve" space as it becomes available, for periods of time, as they assess or await additional funding for expending or starting new activities.

Site and Facilities Objectives

NREL's overall sites and facilities objective is to provide cost-effective research facilities appropriate to a world-class laboratory that enable meeting DOE program objectives. To accomplish this, NREL's long-term goals for facility planning are:

- Maintain the current physical assets
- Provide state-of-the-art laboratories and equipment
- Reduce the use of leased space
- Maximize efficiency by consolidating operations as much as possible
- Provide flexibility to accommodate uncertainty in future growth and program directions
- Design sites and facilities to attract high-quality staff, foster a cohesive identity, and enhance staff communications and interactions
- Exemplify sustainability in an R&D organization by maximizing efficient use of all resources and serving as a positive force in economic, environmental, and community responsibility
- Be a good community neighbor
- Meet or exceed environment, safety, and health regulations, orders, and codes

If these goals are pursued and adequately funded, NREL will be able to cost-effectively meet DOE program objectives (including being able to attract and retain quality staff), maintain and enhance the value of the DOE assets at NREL, and ensure good stewardship of the Laboratory.

Site and Facilities Investment Strategies

NREL has identified these specific near-term strategies to guide site and facilities investments:

- Maintain, upgrade, and develop critical infrastructure
- Anticipate and respond to change and growth in research programs
- Reduce use of leased space

The specific projects targeted for investment are summarized here and in Table 5. These brief descriptions include investments needed each year (general purpose equipment and small general plant projects) and specific larger projects planned for the five-year period, FY 2002-FY 2006.

General Purpose Equipment. This investment replaces and upgrades NREL's general capital equipment at a steady annual rate. Specific equipment needs are identified at the time of budget submission and reevaluated as funding becomes available. This equipment includes:

- Upgrades to NREL's information technology systems, to keep these systems near state-of-the-art in this rapidly changing area
- Upgrades and additions to NREL's scientific instrumentation shared by several programs or projects, to replace equipment that is no longer reliable or serviceable, meet changing research needs, and to keep these instruments near the state-of-the-art in capability
- Additional maintenance, safety, and miscellaneous equipment as needed

Small General Plant Projects. This investment serves to renovate and extend the buildings and infrastructure already in place, and sometimes to further develop the NREL sites. These projects apply to both the STM and NWTC sites. Specific projects are identified at the time of budget submission and reevaluated as funding becomes available. These projects can include:

- Upgrades to utilities, HVAC systems, and related systems within buildings

- Energy efficiency improvements within buildings
- Safety improvements within buildings
- Small expansions of existing buildings or small additional buildings to accommodate changes or growth in R&D programs or research support needs
- Expansions and upgrades of site-wide utility systems (such as electrical, water, sewer/septic, natural gas, telecommunications and computer networks)
- Addition of onsite electrical generating capacity
- Road, parking, and traffic infrastructure improvements
- Walkway, landscaping, water management, water treatment, and other site improvements to enhance the sustainability, cohesiveness, and pedestrian nature of the sites

Science and Technology Facility. This proposed new building would be a 45,000-ft^2 laboratory building to relieve overcrowding in the Solar Energy Research Facility, and respond to research program changes in related areas. This facility will support both fundamental and process research in photovoltaics, hydrogen, superconductivity, and materials science. This facility would also assist in moving some laboratory work out of Building 16 leased space.

Field Test Laboratory Building Expansion. The Laboratory has identified an opportunity to add an expansion to the front of this versatile, often-modified building to provide office space for as many as 90 researchers. This would be a major help in moving researchers out of Building 16 leased space. This expansion would benefit researchers in Hybrid Vehicles, Fuels Utilization, Industrial Technologies, Biomass Power, Hydrogen, and others.

Field Test Laboratory Building Internal Build Out (Phase I). Previous modifications to this building left opportunities to reconfigure internal space to add laboratories and offices. This project would build out some of this internal space, again assisting in moving laboratories and researchers out of Building 16 leased space, as well as providing some flexible laboratory space for future program changes or expansions. This project would not build out all potential space within the current building envelope, however; additional laboratories and high-bay space could be built out later when further needs are identified. By providing additional wet laboratories, this project would potentially benefit researchers in many areas, including Biofuels, Industrial Technologies, Biomass Power, Hydrogen, Office of Science/Basic Energy Sciences Chemical Sciences, Biological Sciences, Concentrating Solar Power, Geothermal, and Solar Heat and Buildings.

Clean Energy Systems Test Site. This project would develop the facilities (a laboratory building, outdoor test pads, infrastructure, and general equipment) needed to test distributed and hybrid electrical generation systems. Developing and testing distributed and hybrid power systems is one of NREL's major initiatives for the next five years, including renewable energy systems as well as natural gas, fuel cell, hybrid, and other small generating systems. The near-term focus for this test site would be to address interconnectivity issues and standards development as a DOE user facility.

Thermal Test Facility Expansion. NREL currently has a 10,000-ft^2 building used for both building energy and transportation-related R&D. This building is being used beyond its intended capacity, and additional research needs are not being met. This project would expand this building by about 50% in floor space.

NWTC Electrical Infrastructure Upgrade. As the Wind Energy Program studies larger and larger turbines in the future, the electrical system at the NWTC will need to be significantly enlarged and upgraded.

Structural Blade Testing Facility. Intended for the NWTC, this facility would augment the existing blade testing facilities and add a small wind tunnel for expanded testing capabilities.

10 MW Dynamometer Test Facility. The NWTC has a dynamometer test facility to test small (up to 2.5 MW) wind turbines, but program needs anticipate that a much larger facility will be needed to meet future generations of turbines.

Bioenergy Research Facility. Bioenergy is one of NREL's major initiatives for the future. Current biological, chemical, and related laboratory research (and small-scale process development research) is conducted in the Field Test Laboratory Building. As noted, this building requires expansion and buildout to meet current research needs and to move some of the research and researchers out of leased space in Building 16. Anticipated expansion in bioenergy research will require additional research laboratories beyond what is currently planned for the Field Test Laboratory Building. The proposed Bioenergy Research Facility would provide an additional 50,000 ft^2 of laboratory space for the full range of bioenergy research.

Research Support Facility. This new building would house all the staff currently in leased facilities. It is intended to be a showcase for sustainability, with very low energy usage. Concepts are in the initial design stages.

Clean Energy Systems Test Site Expansion. This project would allow for anticipated expansion several years from now in the programmatic and research areas mentioned above. An expanded test site would be able to conduct distributed power R&D beyond interconnectivity issues, and demonstrate all distributed power technologies.

Advanced Bioprocess Development Facility. Expanded bioenergy research will require not only laboratory and small-scale process development research, but pilot-scale process devel-

Table 5. NREL Five-Year Construction Plan, FY 2002-FY 2006

	Tentative Funding*	FY '00	FY '01	FY '02	FY '03	FY '04	FY '05	FY '06
General Purpose Equipment	GPE	$450	$1,500	$1,940	$1,500	$1,500	$2,000	$2,000
Small General Plant Projects	GPP	$650	$400	$2,140	$2,500	$2,500	$2,500	$2,500
Science and Technology Facility	CLI			$12,700				
FTLB Expansion	GPP			$3,000				
FTLB Internal Build Out	GPP			$4,000				
Research Support Facility	CLI				$55,000			
Clean Energy Systems Test Site	CLI				$9,000	$3,000	$3,000	
Thermal Test Facility Expansion	GPP				$1,500			
NWTC Electrical Infrastructure Upgrade	GPP				$3,000			
Structural Blade Testing Facility	GPP					$3,000		
Bioenergy Research Facility	CLI					$10,000		
10 MW Dynamometer Test Facility	CLI						$15,000	
Clean Energy Systems Test Expansion	GPP							$4,500
Advanced Bioprocess Dev. Facility	GPP							$5,000
Science & Technology Facility Expansion	CLI							$10,000
Total		$1,100	$1,900	$23,780	$72,500	$20,000	$22,500	$24,000

*GPP = General Plant Projects
GPE = General Purpose Equipment
CLI = Construction Line Item

opment research. NREL's current Alternative Fuels User Facility focuses on only one type of bioenergy, ethanol from biomass. Future research directions will require an R&D facility similar in concept but for integrated production of fuels, chemicals, heat, and electricity.

Science and Technology Facility Expansion. Anticipated expansion in the programmatic research areas mentioned above.

Integrated Safety Management

As a DOE national laboratory, NREL takes the safety and environmental well being of its workers and that of the surrounding community as one of its highest priorities. This attitude not only results in a safe work environment, it also promotes NREL to the community as a good neighbor; plus, it meshes naturally with the mission and vision of the Laboratory.

Starting in 1996, NREL began to implement Integrated Safety Management (ISM) because it was the most efficient and effective path to ES&H performance and because it was viewed as a best management practice. Integrated Safety Management is a concept whereby many elements of ES&H are integrated into Laboratory management activities, including strategic and operational planning, quality assurance, and performance assessment. It is a concept whereby managers and workers at all levels participate in the ES&H activities. But at NREL, ISM is more than a set of procedures, or checklist. It is a way of life in which ES&H activities become fused into the organizational culture at every level — from top management to ES&H staff, to laboratory researcher, to construction and temporary worker.

Executive management participates in ISM by setting and endorsing ES&H policies, by providing resources for ES&H activities and by serving as members in and chairing (Laboratory Director) the Safety Council. This council meets periodically to develop and recommend ES&H performance objectives, to assess performance against those objectives, and to address work issues and concerns.

Senior and line managers also participate in the Safety Council. But their responsibilities also run the gamut from implementing ES&H programs into their organizations and into their strategic and operational planning, to resolving ES&H issues for their organizations, to making sure that their workers receive ES&H training.

Workers take part by making sure they attend periodic training classes, by following safety procedures at all times, by complying with safety rules and regulations and standard operating procedures (SOPs), and by also participating on the Safety Council. Workers also have the responsibility to report any incident or any unsafe condition or procedure — in fact, a worker may intervene in and stop any activity they deem as a threat to the health or well being of others.

Finally, the ES&H Office acts as coordinator and implementer of all ES&H policies. It develops the ES&H program, implements it, and provides its oversight. It defines and provides processes for assessing risks and for identifying and controlling hazards. It develops and documents procedures for ES&H programs (such as for electrical safety, biosafety, chemical safety, bloodborne pathogen control, ergonomics, and much more) and for SOPs (which are implemented by workers involved in specific tasks that require SOPs). It provides ES&H training for all workers. And it coordinates ES&H matters with internal and external agencies.

Due to the early implementation of ISM practices and the cooperation evident across all levels of the Laboratory, NREL has already been through the first two phases of the verification process.

Information Management

In FY 1998, the Laboratory began a series of projects to improve the capabilities of NREL's three computing environments — scientific & technical computing; productivity, collaboration & knowledge management; and business management (Figure 34). Upon completion in FY 2000, some of the improvements these projects will have implemented include:

- Y2K-compliance across the Laboratory's IT environment, including major business systems, critical lab equipment, and PC/Mac desktops
- Business system improvements that provide increased integration and sharing of data across systems, and that move the Laboratory towards intranet-based self-service applications
- A centralized, Laboratory-wide messaging system that supports NREL's mixed PC/Mac desktop environment
- Core desktop applications for both PC's and Mac's that implement standard file formats for easier exchange of information
- Anti-virus protection that encompasses desktops, file and print servers, and Laboratory-wide messaging system
- Centralized desktop management, including asset management, electronic software distribution, remote diagnosis and repair
- Increased Intranet security via firewall implementation
- Improved networks, including increased bandwidth, more security and more flexible configuration management

Over the next five years, NREL will continue to make improvements to enable the three computing environments to meet the considerable challenges posed by changing business requirements and by the evolution of technology and culture.

For example, the way in which NREL's researchers and developers perform their work will change dramatically. Scientific collaboration will move farther beyond the walls of the Laboratory, supported by secure, high-speed networks and advanced models and information management tools. Enhanced inter-Lab (and Lab-to-industry) collaboration, in the form of video and audio conferencing, application-sharing, and remote access to instrumentation will become business as usual. As computing power increases, and advanced simulation tools become more available, more and more research will occur in 'virtual' labs, where experiments take place in a simulated laboratory environment or virtual pilot plant, rather than in the traditional laboratory environment. As growth in conducting scientific R&D process in the digital realm occurs, Laboratory Information Management Systems (LIMS) and scientific computing will become more important. The Laboratory will use LIMS to manage all aspects of the lab

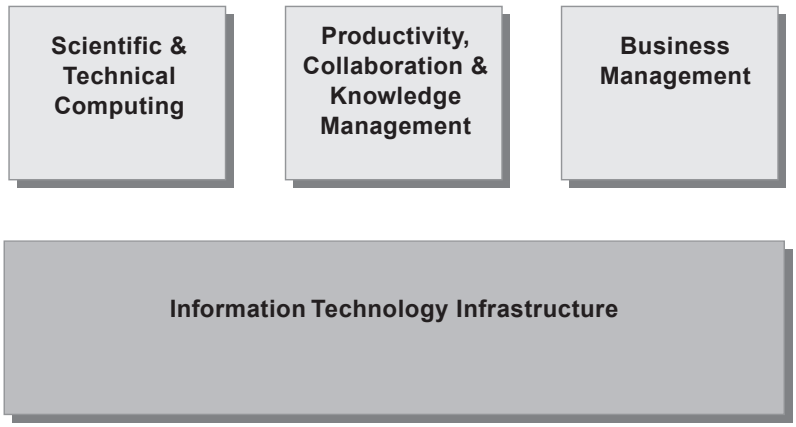


Figure 34. NREL's three major computing environments are supported by a fourth — the underlying IT infrastructure.

process with an eye towards knowledge capture and improving workflow efficiency.

Advances in IT will also yield new desktop tools and techniques that, in turn, will enable individuals and groups to leverage the Laboratory's knowledge base to increase productivity. NREL's Intranet will serve as the primary transport and delivery medium, as applications and operating systems become more integrated with the Web and the Internet, and 'Webtops' begin to replace 'desktops'. More and more of the Laboratory's knowledge will be 'digital', whether it be instrumentation data, Word documents, project management information, contact lists, Web sites, videoconferences or group discussions — it will all be captured (and managed) electronically.

People will become less tied to physical office space, both within NREL and without. Networks will allow access to 'desktops' from any networked computer in the Laboratory. Dynamic workgroups will have easy access to critical information without a dependency on physical location. Using secure, high-bandwidth connections, NREL's IT infrastructure will enable the Laboratory to access a wide range of capabilities and resources.

Consistent with these envisioned changes and with the demands of NREL's critical outcomes, the Laboratory has set five strategic goals for its computing environments:

- Develop and implement an advanced computing and networking architecture that supports high-performance scientific/technical computing and enables achieving the performance objectives associated with the Science, Technology, and Deployment critical outcome
- Provide tools to simplify and improve the discovery and communication of information and knowledge needed to solve scientific and technical problems
- Enable natural, timely electronic communication and collaboration for work teams regardless of location or organization
- Support enhanced, yet ubiquitous, productivity, independent of location or device
- Utilize integrated information systems and real-time access to critical data to support the development of client and stakeholder relationships, facilitate project management, and manage our investment portfolio

Science and Technology Education Programs

NREL's Office of Science and Technology Education is committed to leveraging the many resources at NREL, both technical and human, to strengthen science, mathematics, and technology education for all students, and to increase the quantity, quality, and diversity of students preparing to be scientists and engineers. Toward this end, we have established three overarching thrusts:

Develop a Capable, Diverse Workforce.
NREL's Science and Technology Education Programs reach students at all levels. Included are tutoring and hands-on science activities for young students in after-school programs. For secondary students, NREL sponsors awards, recognition, and special events, such as the Junior Solar Sprint and DOE's Science Bowl competition.

Undergraduate and graduate students participate in mentored laboratory research internships and fellowships. These students play a vital role in NREL's research and technology enterprise and gain valuable research experience as part of their training. Research participation programs, such as DOE's Research Undergraduate Laboratory Fellowships, are instrumental in encouraging students to explore careers in energy efficiency and renewable energy.

Contribute to Excellence in Teaching and Learning. NREL contributes to improving the education system so that all students understand science and technology fundamental to renewable energy and energy efficiency. To meet the challenges and demands that face the nation in the new century, all citizens will need a high level of scientific and technical literacy to succeed.

Because of their role in reaching students at all levels, teachers are offered research participation opportunities to enhance their content knowledge, instructional strategies, and leadership abilities. Through a partnership with Mathematics, Engineering, and Science Achievement, NREL supports teachers in schools with large populations from underrepresented groups, such as ethnic minorities and women.

NREL also engages in partnerships and collaborations with education organizations, such as the Colorado Mathematics and Science Education Coalition to improve critical elements of the education system in science, mathematics, and technology.

Build Strong Research and Education Partnerships. Connecting research and education leads to innovation. NREL fosters innovation by partnering with colleges and universities to advance the research, development, and deployment of sustainable energy technologies. For example, the DOE provides support at NREL for a partnership with Historically Black Colleges and Universities.

In turn, collaborating with NREL helps build educational excellence in academic programs. NREL and universities engage in joint research projects; faculty and postdoctoral fellowships and sabbaticals; adjunct faculty arrangements; scientist-faculty exchanges; and facility access, use, and sharing.

Intellectual Property and Deployment

Creating viable technology options that can meet the nation's needs and the missions and goals of DOE and NREL is a multifaceted task that requires a well-planned effort, both intraLaboratory and extraLaboratory. The wellspring for these options are the functional concepts, copyrighted works, inventions, and patented ideas that are the fruit of the insight and labor of NREL scientists, either alone or in partnership with others.

The ideas that arise from the Laboratory and its partners tend to be nascent and need considerable development by the private sector before becoming commercially viable. Therefore, to properly develop and transfer technology in a way that protects the interests of NREL and DOE and that maximizes benefits to the consumer, NREL carefully manages intellectual property by shepherding candidate concepts through U.S. and international patent processes, developing commercialization strategies, and engaging in a variety of outreach activities with the energy industry to define and implement pathways to transfer

Table 6. Output of NREL Intellectual Property & Technology Transfer

	FY '97	FY '98	FY '99
Inventions	36	49	51
Patent Applications	19	18	34
Licenses	1	3	7
CRADA/WFO/ASA*	3	25	48

**Cooperative research and development agreements, work for others, and analytical service agreements — direct ways in which NREL transfers technology and know-how to others.*

Laboratory intellectual property to the private sector.

Having developed streamlined procedures for intellectual property management and tightened linkages between its technical centers and the Technology Transfer Group in 1999, NREL is moving to a much more active approach in deploying technologies. We will, for example, develop marketing strategies, identify where technical work would enhance the attractiveness of intellectual property to the private sector, and target specific industries for licensing. We will also develop a Tech Transfer database that will enable us to store and integrate related information on inventions, patents, CRADAs, WFOs, and more.

Further, NREL intends to develop an incubator alliance. This will be an alliance with five or six top-tier, high-profile regional incubators from across the nation. The alliance will act as a catalyst for the growth of clean energy technologies and companies. It will stress helping start-up companies develop a business and market focus (vis-à-vis a technology focus). The alliance will support NREL licensees, and spinout companies, and NREL's current and past sub-contractor R&D partners. It will also incorporate NREL's current Industry Growth Forums (which bring together financiers and executives of renewable energy companies).

This alliance will be national in scope and provide local access to a rich source of business and financial resources. It will provide natural linkages to Industry Growth Forums, including network of venture capitalists, to the NREL Business Advisory Network, to NREL green marketing and market sector activities, and possibly to the Battelle "Break Through Center."

By implementing this alliance NREL will meet its strategic objectives to strengthen linkages to major EERE stakeholders, and to increase placement of intellectual property into the private sector. This alliance will also directly address NREL's five-year plan "major accomplishment" to establish an EERE incubator capability.

Director's Discretionary Research and Development Program

Technical innovation is critical to the viability and success of NREL and to the DOE programs it supports. An important avenue for encouraging innovation at NREL is the Director's Discretionary Research and Development (DDRD) program. The program enables the director to approve funding for projects proposed by laboratory staff that explore and develop innovative or creative concepts within NREL's mission.

The DDRD is closely integrated with the Laboratory's key technical thrusts for the future. For the next five years this includes bioenergy, distributed and hybrid generation, basic science, and energy from simple molecules. Of the 18 new proposals funded in FY 1999, five were funded on bioenergy projects, nine on distributed and hybrid generation, and two on energy or fuels from simple molecules. Of these, four are basic science projects.

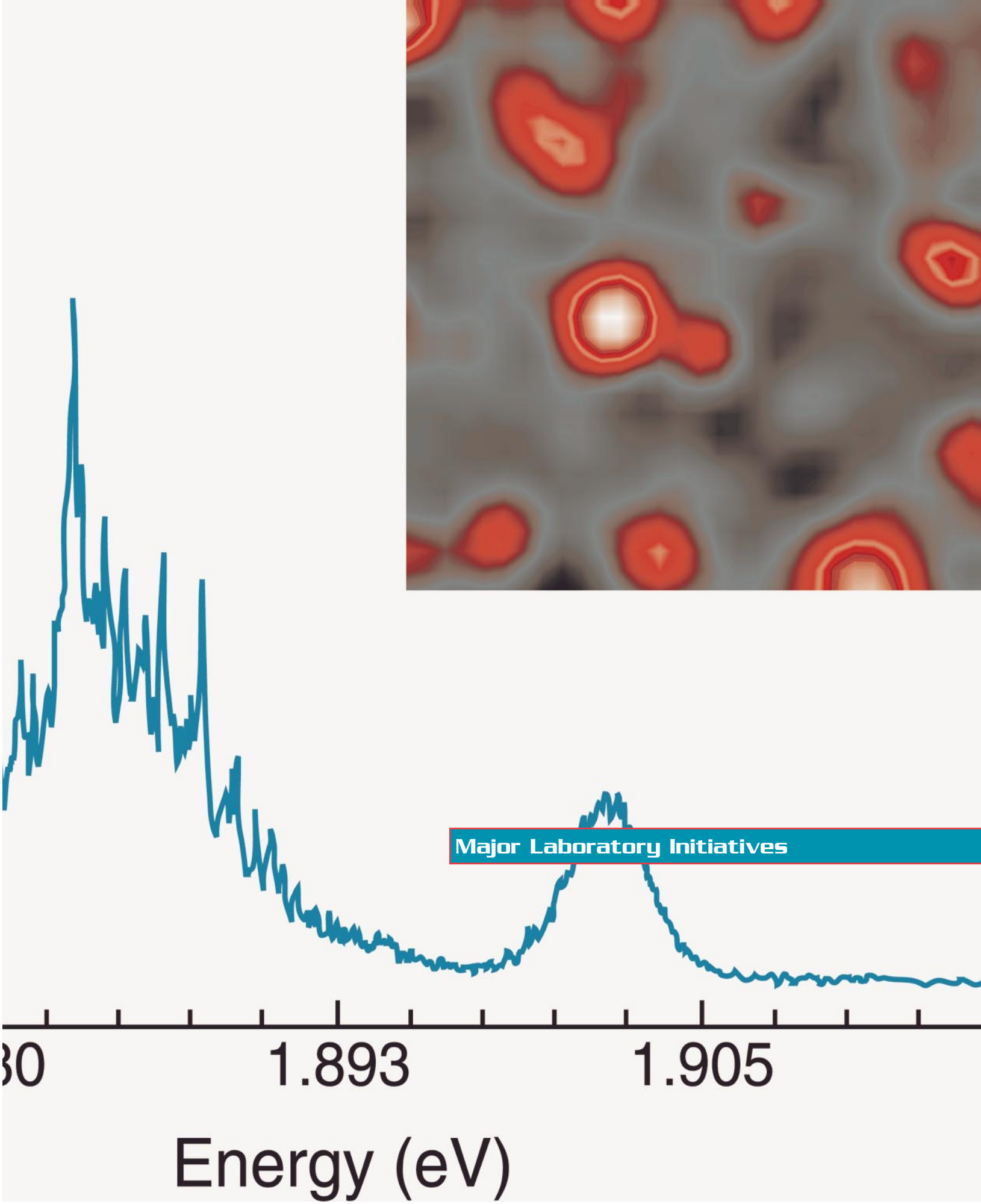
The DDRD program yields innovations that seed new program directions and strengthen NREL capabilities. In addition, the projects produce a significant number of publications, as well as intellectual property such as records of invention and patents, keeping NREL at the forefront of innovative science. Of the 28 active projects during 1999, there were many noteworthy outcomes, including:

- The development of a concept for applying NREL's photocatalytic oxidation technology to killing airborne pathogens. This technology can be used in a variety of applications,

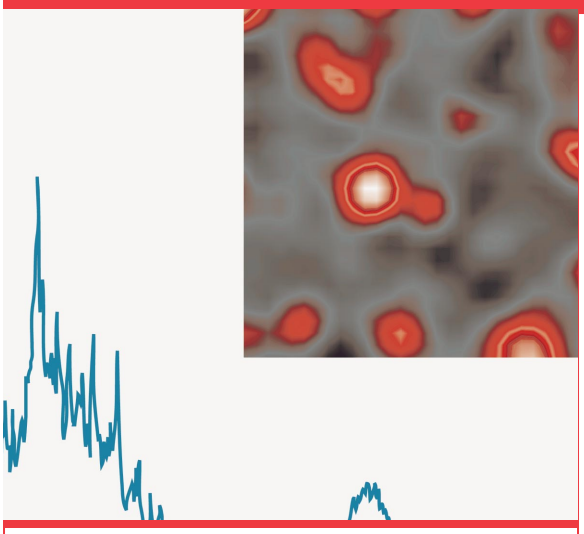
including "sick" buildings, hospitals, aircraft cabins, and the space shuttle. This work has led to a record of invention and to a series of collaborations with other agencies and programs.

- The synthesis of inorganic fullerenes using laser vaporization. This has potential for a number of applications relevant to NREL's mission: batteries, catalysis, water splitting, and optoelectronic technologies. NREL scientists filed a patent and published the results of this groundbreaking research in the journal, *Nature*.
- The proof-of-concept of producing thermoplastics with 4- and 5-carbon polymer repeat units from a 2-carbon feedstock using a photobacterial system. This research enhances NREL's existing photosynthesis microbiology competency and links it with other NREL capabilities in polymer characterization and testing, and reactor design and analysis, to establish a new area for the Laboratory.

The DDRD program will continue to be the source of technology innovation and cutting-edge scientific advances, which ensure technical vitality of the Laboratory and keep the scientists at the forefront of their fields. The impact of the results from this program will continue to be far reaching — from basic research underpinning the technology to new technology developments that have commercial potential for the Laboratory's many stakeholders.



Major Laboratory Initiatives



Spatially resolved Photoluminescence. This frame shows the photoluminescence spectrum taken at the center of a 5- x 5-um area of a $GaInP_2$ epilayer. The inset shows the spatial variation in the photoluminescence at the indicate spectral energy.

The National Renewable Energy Laboratory is pursuing five initiatives to help the Laboratory meet its mission, to strengthen its core capabilities, and to enable the Laboratory to respond to current and anticipated needs of the DOE. The initiatives are:

- Bioenergy
- Basic Energy Research
- Carbon Management
- International and Environmental
- Distributed Power and Hybrid Generation

Each of these initiatives supports several of the goals of the DOE Strategic Plan, the EERE Strategic Plan, and the thematic goals of the Office of Science. The initiatives are provided for the consideration by the Department of Energy. Their inclusion in this plan does not imply DOE's funding approval or intent to implement them as initiatives.

Bioenergy

During the latter part of the 20th century, our nation's economy became increasingly dependent on imported fossil fuels. Biomass represents an enormous and relatively untapped renewable resource that has the potential to displace or supplement fossil fuels in many applications such as transportation fuels, power for buildings and industry, and feedstock for the production of chemicals, fiber, materials, pharmaceuticals, and a variety of products. The Department of Energy, along with other federal agencies and private partners, is launching a national partnership to develop an integrated industry to produce power, fuels, and chemicals from residues and dedicated crops.

On August 12, 1999 President Clinton issued Executive Order #13134, Developing and Promoting Biobased Products and Bioenergy, and called for a coordinated effort to accelerate the development of a 21st century U.S. biobased industry. This emerging industry holds the potential for providing significant sources of renewable energy that can also mitigate substantial amounts of greenhouse gas emissions by using crops, trees, and their residues to make fuels, chemicals, materials, and electricity. This would provide a sustainable energy source employing indigenous U.S. based resources. The President set a goal of tripling U.S. use of biobased products and bioenergy by 2010 to provide new income for farmers and rural America, provide a homegrown industry sector with jobs, and mitigate carbon from greenhouse gases. The Department of Energy and the U.S. Department of Agriculture (USDA) have formed a Biobased Products and Bioenergy Coordination Office as directed by the Executive Order to carry out the directives within the Executive Order and supporting Memorandum.

With this call from the President, NREL's existing and future efforts in bioenergy have been given a strong impetus to move forward. NREL has been a partner with Oak Ridge National Laboratory for 20 years in the business of bioenergy. The two laboratories will be teaming in many areas to foster the growth and development of a bioenergy industry within the United States. The following are the efforts that will be undertaken in this initiative by NREL and ORNL as requested by DOE:

- Provide technical support to the federal agencies, DOE and the USDA, in writing a strategic plan for the President
- Undertake analysis efforts in support of the business of bioenergy. The two laboratories have done extensive analyses for processes, biomass resources, and bioenergy systems
- Assist DOE in developing an inventory of federal R&D in biobased products and bioenergy related fields and that is catalogued by federal agency, performer, and focus

- Better define the roles of NREL and ORNL in the implementation of the Executive Order: in the development of the DOE initiated Bioenergy visioning and roadmapping efforts and in assisting DOE with developing Requests for Proposals for FY 2000 and beyond
- Define and explore collaborations with other laboratories (DOE, USDA, and EPA), universities, and industry to enhance the research contributions to the business of bioenergy for NREL, DOE, and the nation
- Explore and establish working relationships between NREL and ORNL in collaborative R&D in several areas including plant biotechnology, bioprocessing, resource assessment, carbon management, and systems analysis
- Examine and explore opportunities for biosciences R&D that can serve as the foundational sciences in support of applied R&D in biobased products and bioenergy. The DOE Office of Science would be the main target of opportunity but other avenues would be examined including EPA and other federal agencies

In addition, NREL and ORNL will assess the viability of a National Bioenergy Center that can serve as a focal point for the efforts of both laboratories. NREL/ORNL will specify to DOE the benefits of designating the two laboratories as a virtual center with joint operations in support of DOE bioenergy efforts and internal bioenergy and biobased products research and development. Some of these benefits are:

- Integrate existing capabilities across multiple organizations
- Provide streamlined access in support of DOE objectives
- Provide a mechanism for identifying and filling capability gaps
- Integrate strategic and multi-year planning to assure optimum use of government laboratory, university, and industry resources
- Develop and use validated data, tools, and integrated models
- Provide a center for information, data, tools, and models
- Provide technical assistance to industry and universities
- Support existing sector programs
- Leverage DOE's biomass resources with the life and plant science capabilities of DOE and of other agencies.

NREL and ORNL also continue to evaluate different approaches to teaming with other laboratories, universities, and industry, to strengthen the National Bioenergy Center and to implement the Executive Order.

Basic Energy Research

Resolving problems along the development path of any technology and assuring the development of next-generation and advanced concepts requires deep knowledge of the fundamental physical, biological, chemical, material and engineering properties and phenomena underlying these technologies. NREL conducts basic research in many areas to support renewable energy technologies. This basic research includes new materials for photovoltaic devices; conversion of sunlight to energy and products through photoelectrochemistry, photobiology, and photocatalysis; fundamental heat transfer studies; electrochemistry techniques to manage carbon; genetic engineering of biomass; and other areas.

Rapid advances in a number of fields, including massively parallel computing, genetic engineering and biotechnology, materials and chemical sciences, and nanoscale science can lead to breakthroughs in applied energy technology research and development. These breakthroughs depend on a robust effort in basic research that is well integrated with the strong applied technology base that forms the core of NREL's mission for DOE. Strengthening the

basic research foundation of the Laboratory will contribute to the fourth goal of the Comprehensive National Energy Strategy — Expand Future Energy Choices — by yielding alternative energy pathways for renewable energy and energy efficiency technologies.

One area of emphasis over the next five years is to enhance the Laboratory's capabilities in scientific computing. This includes simulation and modeling of physical phenomena using high performance computers, visualization of large data sets to extract useful information, and distribution and storage of these data sets. This capability will enable NREL to predict properties before, or instead of, measuring them; properties related to chemical kinetics of biomass, phase diagrams for processing materials, hydrodynamics and aerodynamics for wind turbines, failure and fatigue of materials under extreme conditions, development of nanostructures and high-efficiency materials for photovoltaics, and carbon nanotubes for hydrogen storage.

Another area of emphasis will be plant biosciences. NREL proposes to advance the scientific understanding that will enable plant systems to be managed for efficient production of bioenergy and bioproducts, with awareness of the related affects on carbon dioxide emissions and atmospheric carbon concentrations. Technical areas for study include genomics and gene expression, photosynthesis and respiration, cell wall assembly, nutrient use efficiency, biotic and abiotic stress, and plant metabolism.

In addition to these two areas of emphasis, the initiative will also support partnerships between the Office of Energy Efficiency and Renewable Energy and the Office of Science, enhancing the integration of basic and applied research. The participants and stakeholders for this initiative include the Office of Energy Efficiency and Renewable Energy, the Office of Science, DOE national laboratories, universities, and premier research laboratories around the world.

Carbon Management

The rise in greenhouse gas emissions from fossil fuel combustion to provide energy, and industrial and agricultural activities, has aroused international concern about the possible impacts of these emissions on climate. The primary greenhouse gas contributing to this concern is carbon dioxide. Long-term solutions to the increasing concentrations of carbon dioxide in the atmosphere will require multiple approaches. The concentration of carbon dioxide in the earth's atmosphere can be affected by using energy more efficiently, by reducing the use of carbon-rich fuels in favor of carbon-poor or non-carbon fuels, and by capturing and sequestering carbon.

Since its establishment in 1978, NREL has been involved with carbon management both directly and indirectly. The Laboratory, for example, is currently undertaking research efforts to understand the chemistry of carbon dioxide conversion into higher value materials and the biology of the processes that produce or consume greenhouse gases. This initiative will expand our efforts in these two research arenas and will expand the understanding of the chemistry and biology of greenhouse gas emissions occurring naturally and anthropogenically. The initiative will also help NREL develop collaborations with other national laboratories, federal agencies, and academic institutions where NREL's expertise and capabilities logically fit into larger program efforts.

Employing renewable energy in our nation's energy mix avoids the production of significant amounts of greenhouse gases or mitigates its impact on the environment. Use of biomass for energy, materials and products is approximately carbon neutral in that nearly as much carbon dioxide is consumed by photosynthesis as is emitted by converting biomass into energy or products. In addition, there is a need to manage the steady growth of carbon dioxide that occurs as our economy grows but even more so

as the economy of other countries grows even faster than ours. One way in which to manage carbon dioxide is to use it as a resource and not just consider it a waste product to be dumped into the atmosphere.

This initiative will explore carbon dioxide as a resource. As such, it will drive the development of renewable energy technologies. It will stimulate research into conversion of carbon dioxide into fuels and chemicals. And it will stimulate research opportunities in areas that complement energy production or energy efficiency. Specifically, this initiative will involve:

- Research into the basic processes involved in the emission of greenhouse gases produced both naturally and anthropogenically
- Research addressing the use of solar driven conversion of greenhouse gases into fuels and products including novel approaches for direct recovery of CO_2 from the atmosphere
- Research into biological systems that produce alternatives to carbon based fuels such as hydrogen
- Development of analysis tools (experimental and systems) to evaluate various processes, mechanisms, or schemes involved in managing anthropogenic sources of greenhouse gases
- Research that develops expanded uses of carbon that has been fixed photosynthetically by the biome or converted into products and feedstocks with long-lived carbon storage potential. This is being done with both chemical and biological processes.

This effort supports interactions among the Department of Energy, the Environmental Protection Agency, and the U.S. Department of Agriculture, especially the Forest Products Laboratory. NREL is collaborating with the University of Colorado and the University of Oklahoma in solar driven carbon capture and conversion research and with the U.C. Berkeley and Lawrence Berkeley National Laboratory in biological production of hydrogen. Oak Ridge National Laboratory is a partner in research related to photosynthesis and to improving plant genetics for carbon management. In addition, the effort employs facilities at Argonne and Brookhaven National Laboratories and is pursuing partnerships with Historically Black Colleges and Universities.

International and Environmental

The objective of this initiative is to develop partnerships among DOE, other Federal agencies (e.g. AID, EPA, State) and non-government organizations (NGOs) that will lead to the deployment of renewable energy and energy efficiency technologies in developing countries.

Two billion people currently do not have access to electricity or other dependable energy sources, affecting their health, education, and well being. Renewable energy and energy efficiency can help address these needs as well as provide integrated solutions to economic development goals. In addition, expanded use of these technologies will reduce emission of carbon dioxide, the primary contributor to global climate change. The global environmental issue of climate has emerged as a powerful driver for the adoption of renewable energy technologies internationally.

The need for deployment of renewable energy and energy efficiency in developing countries is greater than ever before. Large countries like India and China are taking steps to address their nations' energy problems, presenting opportunities for renewables. Greater political and economic stability in Eastern Europe, the newly independent states of the former Soviet Union, and the Far East offer opportunities as well. From the perspective of the global interests of the United States, it is also critical that DOE and NREL not only maintain their international activities, but expand them. This point is emphasized by the June, 1999 report of the President's Council of Advisors on Science and

Technology (PCAST): "Powerful Partners, Conclusions on the Federal Role in International Cooperation on Energy Innovation." The report points out that:

- U.S. interests and values at stake in energy can only be effectively addressed in a global context
- U.S. economic interests in energy technology innovation include expanding the market share of U.S. companies in the multi-hundred billion dollar per year global energy-technology market
- U.S. security interests in energy-technology innovation include avoiding, for all countries, energy problems with economic, environmental, or political consequences severe enough to aggravate or generate possibilities for armed conflict

NREL has supported the deployment of these technologies with projects and activities in many different countries, providing technical assistance, information, and project management. The Laboratory's proposed activities will be aligned with DOE's international strategic directions. Established relationships with US AID (headquarters and missions), the EPA, World Bank, etc. should serve as a critical asset contributing to the success of efforts to facilitate international deployment.

One of the primary focuses for NREL's international and environmental initiative will be the Technology Cooperation Agreement Pilot Project (TCAPP), which was developed at NREL. On behalf of USAID, DOE, EPA, and the State Department, NREL leads implementation of TCAPP to provide a model for executing technology transfer under the United Nations Framework Convention on Climate Change (UNFCCC). Through this program, NREL is now assisting over 20 developing countries in attracting investment in clean energy technologies that will meet their development needs and reduce greenhouse gas emissions. This program is widely recognized as the most promising model for design of an official technology transfer program under the UNFCCC. Through this program NREL has become the leading international institution on the design and implementation of climate change technology transfer issues.

NREL will also focus on expanding its work on model Clean Development Mechanism and Joint Implementation Projects. Lastly, NREL will also focus on partnerships in development with AID missions, global resource mapping primarily funded through the Global Environmental Facility (GEF), and offerings of our rural electrification assessment tools (HOMER, VIPOR and Regional Assessment) and related analysis and training capabilities to international customers.

Distributed Power and Hybrid Generation

NREL has been working with DOE to evolve a strategy for distributed power systems. A distributed power system can be as simple as a small generator producing emergency backup electricity at an energy customer's site. It might be connected to the grid or not. Conversely, it can be a more complex system composed of generation located near the energy consumer's site, plus energy storage, energy management and combined heat and power, and be highly integrated with the electric grid to provide multiple benefits on both sides of the utility meter. Consequently, distributed power can provide benefits that go well beyond the individual power system user to the electrical grid itself. A properly designed and operated grid-integrated distributed power system would potentially offer lower electric power cost, enhanced reliability and power quality, lower energy use, and/or higher energy efficiency, e.g., combined heat and power. There is also the potential for reduced environmental impacts.

Distributed power development supports national goals, as espoused in the Comprehensive National Energy Strategy, such as supporting the formation of competitive electric systems, increasing energy efficiency, and ensuring system reliability, flexibility, and emergency response capability. In particular, distributed power markets might prove to be some of the most effective paths to true competition in the restructured electric industry, by offering energy consumers additional choice. This is the focus of a five-year planning effort for the DOE Office of Power Technologies, with which the NREL initiative is coordinated.

A major thrust of NREL's mission is to facilitate the deployment of renewable energy and energy efficiency technologies. Under today's U.S. electric market structure, grid-connected renewables in most cases must compete at wholesale prices with bulk power produced by central station generators. Deployed as a distributed power system, however, a renewable generator could potentially provide higher marginal value, and hence enjoy a better competitive position, than in a wholesale central station market. Natural gas is predicted to be the primary fuel for distributed power systems for the foreseeable future. Combinations of natural gas and renewable generation systems, called "hybrids," however, bring many additional benefits, such as increased environmental benefits for natural gas, and a compensation for the intermittency of renewables. Consequently, the vision for NREL's Distributed and Hybrid Generation initiative is that a healthy, distributed power industry and market could provide a highly favorable environment for the deployment of renewables and energy efficiency.

This initiative strives to:

- Support NREL's leadership in the development and adoption of universal electric-grid interconnection standards for distributed power systems
- Explore the need for a testing capability and facility managed or coordinated by NREL to develop and validate interface testing of universal electric-grid interconnection standards in a controlled environment
- Establish NREL as a central clearinghouse for the coordination of missions and protocols of other distributed power systems testing as needed for component and systems operational performance and reliability evaluation on the customer and grid sides of the interface
- Enhance NREL's roles in the development, design and deployment facilitation of renewable and renewable/fossil hybrid distributed power systems in grid-connected applications in the United States

Resource Projections

This section summarizes the funding for the laboratory (operating, capital equipment, and construction), and personnel data (direct and indirect) for various levels. These levels include overall funding and personnel (Tables 7 and 8) and breakdowns by Secretarial Officers (Tables 9 and 10).

The tables reflect the actual funding and full-time equivalents (FTEs) for FY 1998 and FY 1999. Projections for FY 2000 and beyond reflect the Laboratory's request for new budget authority, as of the publication of this document. All funding estimates are given in constant 1999 dollars.

Table 7. Laboratory funding summary ($ in millions – BA).

	FY '98	FY '99	FY '00	FY '01	FY '02	FY '03	FY '04
DOE Operating	165.2	178.0	182.0	185.1	192.2	198.0	202.6
Work for others	6.5	7.4	8.0	9.0	11.0	12.0	13.0
Total operating	171.7	185.4	190.0	194.1	203.2	210.0	215.6
Capital equipment	3.7	2.3	3.1	3.7	4.8	6.9	8.7
Construction	2.2	0.0	0.0	6.2	18.0	16.0	8.2
General purpose equipment	1.8	1.9	0.7	1.7	2.0	2.5	3.0
General plant projects	0.6	2.0	0.4	1.3	5.5	7.0	5.8
Total laboratory funding	179.9	191.6	194.1	207.0	233.4	242.4	241.3

Table 8. Laboratory personnel summary (personnel in FTE).

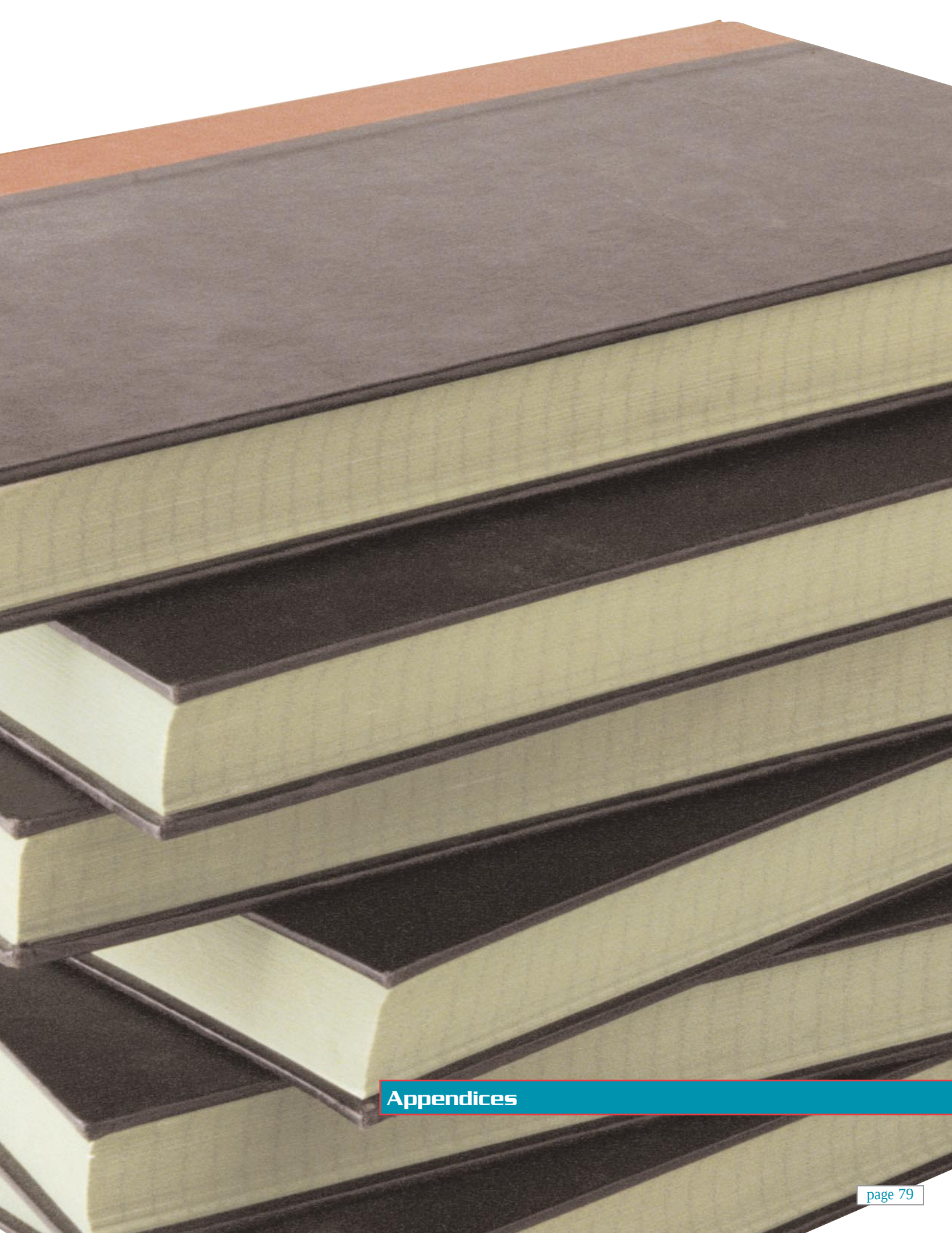
	FY '98	FY '99	FY '00	FY '01	FY '02	FY '03	FY '04
DOE Effort	392.7	388.3	395.3	399.0	416.8	434.3	438.5
Work for others	27.4	26.0	29.7	34.1	39.1	44.8	51.3
Total operating	420.1	414.3	425.1	433.1	455.8	479.0	489.8
Other direct	0.4	1.4	2.0	2.0	2.0	2.0	2.0
Total direct	420.5	415.7	427.1	435.1	457.8	481.0	491.8
Total indirect	386.4	392.0	400.9	408.4	429.9	451.8	462.0
Total laboratory personnel	806.9	807.7	826.0	841.5	885.8	930.8	951.8

Table 9. Funding by Secretarial Officer ($ in millions – BA)

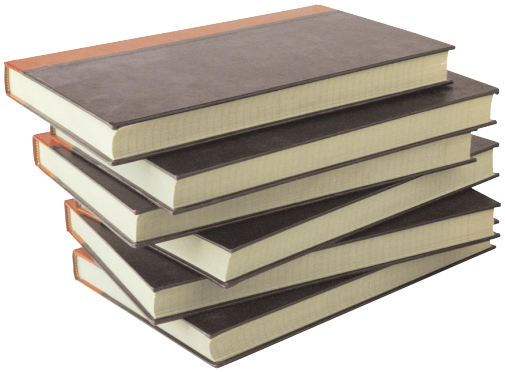
	FY '98	FY '99	FY '00	FY '01	FY '02	FY '03	FY '04
Assistant Secretary for Renewable Energy and Energy Efficiency							
Operating	158.7	170.1	173.5	175.5	181.4	185.4	187.8
Capital Equipment	3.2	1.9	2.5	3.0	4.0	6.0	8.0
Construction	2.2	0.0	0.0	6.2	18.0	16.0	8.2
General Purpose Equipment	1.8	1.9	0.7	1.7	2.0	2.5	3.0
General Plant Projects	0.6	2.0	0.4	1.3	5.5	7.0	5.8
Subtotal Funding	166.4	176.0	177.1	187.7	210.9	216.9	212.8
Director, Office of Science							
Operating	4.7	4.3	5.0	5.9	6.8	8.1	9.8
Capital Equipment	0.5	0.3	0.6	0.7	0.8	0.9	0.7
Subtotal Funding	5.3	4.6	5.6	6.6	7.5	9.0	10.5
Arms Control and Nonproliferation							
Operating	1.5	3.2	3.0	3.0	3.0	3.0	3.0
Capital Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal Funding	1.5	3.2	3.0	3.0	3.0	3.0	3.0
Other DOE							
Operating	0.3	0.3	0.5	0.8	1.0	1.5	2.0
Capital Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal Funding	0.3	0.3	0.5	0.8	1.0	1.5	2.0
Total DOE Funding							
Operating	165.2	178.0	182.0	185.1	192.2	198.0	202.6
Capital Equipment	3.7	2.3	3.1	3.7	4.8	6.9	8.7
Construction	2.2	0.0	0.0	6.2	18.0	16.0	8.2
General Purpose Equipment	1.8	1.9	0.7	1.7	2.0	2.5	3.0
General Plant Projects	0.6	2.0	0.4	1.3	5.5	7.0	5.8
Total DOE Funding	173.4	184.1	186.1	198.0	222.4	242.4	241.3
Work for Others							
Other Federal Agencies	2.9	3.8	4.1	4.4	4.7	6.5	7.5
Non-Federal Agencies	1.1	1.3	1.4	1.5	1.6	2.2	2.5
Cosponsor Supported R&D	0.4	0.7	0.7	0.8	0.8	1.1	1.3
Subtotal Work for Others	4.4	5.7	6.1	6.6	7.1	9.8	11.3
Transfers and Others	2.1	1.7	1.9	2.0	2.2	3.0	3.4
Subtotal Funding	6.5	7.4	8.0	9.0	11.0	13.0	15.0
Total Laboratory Funding							
Operating	171.7	185.4	190.0	194.1	203.2	225.6	233.3
Capital Equipment	3.7	2.3	3.1	3.7	4.8	6.9	8.7
Construction	2.2	0.0	0.0	6.2	18.0	16.0	8.2
General Purpose Equipment	1.8	1.9	0.7	1.7	2.0	2.5	3.0
General Plant Projects	0.6	2.0	0.4	1.3	5.5	7.0	5.8
Total Laboratory Funding	179.9	191.6	194.1	207.0	233.4	258.0	259.0

Table 10. Personnel by Secretarial Officer (Personnel in FTE)

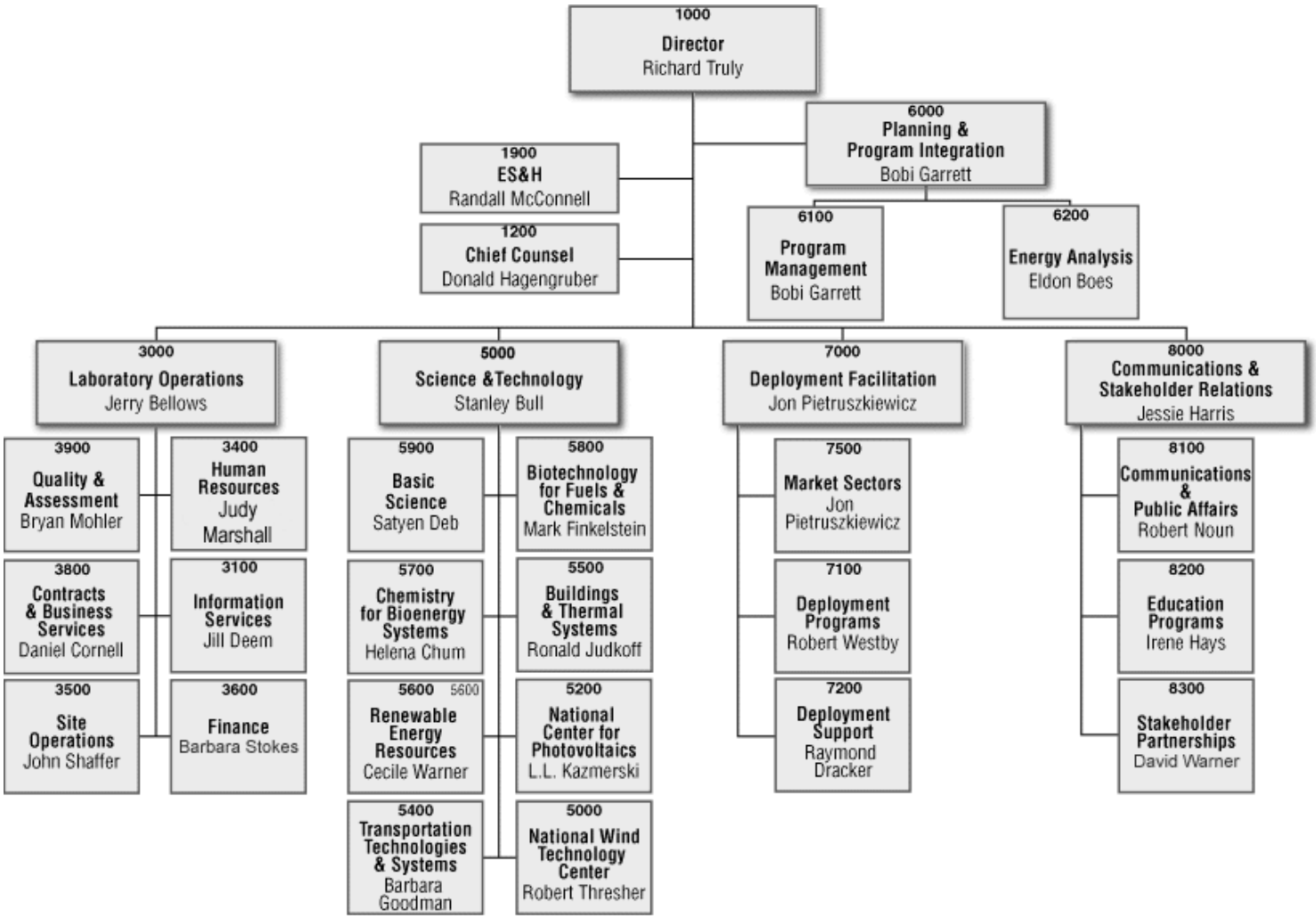
	FY '98	FY '99	FY '00	FY '01	FY '02	FY '03	FY '04
Assistant Secretary for Renewable Energy and Energy Efficiency							
Operating	357.3	356.5	358.0	355.2	368.2	375.5	368.2
Capital Equipment	0.4	0.6	1.0	1.0	1.0	1.0	1.0
Construction	0.1	0.0	0.0	0.0	0.0	0.0	0.0
General Purpose Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
General Plant Projects	0.0	0.8	1.0	1.0	1.0	1.0	1.0
Subtotal	357.8	358.0	360.0	357.2	370.2	377.5	370.2
Director, Office of Science							
Operating	30.1	26.0	29.8	35.8	40.6	48.0	59.0
Capital Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal	30.1	26.0	29.8	35.8	40.6	48.0	59.0
Arms Control and Nonproliferation							
Operating	2.0	2.3	2.1	2.1	2.1	2.1	2.1
Capital Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal	2.0	2.3	2.1	2.1	2.1	2.1	2.1
Other DOE							
Operating	0.3	3.5	5.2	7.8	10.3	15.5	20.7
Capital Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal	0.3	3.5	5.2	7.8	10.3	15.5	20.7
Total DOE Personnel							
Operating	392.7	388.3	395.1	400.9	421.3	441.9	449.9
Capital Equipment	0.4	0.6	1.0	1.0	1.0	1.0	1.0
Construction	1.0	0.0	0.0	0.0	0.0	0.0	0.0
General Purpose Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
General Plant Projects	0.0	0.8	1.0	1.0	1.0	1.0	1.0
Subtotal	393.1	389.7	397.1	402.9	423.3	493.9	451.9
Work for Others							
Other Federal Agencies	6.6	10.3	10.3	12.0	12.9	14.0	15.0
Non-Federal Agencies	17.8	13.6	13.6	15.8	17.0	18.4	19.8
Cosponsor Supported R&D	3.0	2.1	2.1	2.4	2.6	2.8	3.0
Subtotal	27.4	26.0	26.0	30.2	32.6	35.1	37.9
Total Laboratory Personnel							
Operating	420.0	414.2	423.1	431.1	453.8	477.0	487.8
Capital Equipment	0.4	0.6	1.0	1.0	1.0	1.0	1.0
Construction	0.1	0.0	0.0	0.0	0.0	0.0	0.0
General Purpose Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
General Plant Projects	0.0	0.8	1.0	1.0	1.0	1.0	1.0
Total Direct Personnel	420.5	415.6	425.1	433.1	455.8	479.0	489.8
Total Indirect Personnel	386.4	392.0	400.9	408.4	429.9	451.8	462.0
Total Laboratory Personnel	806.8	807.7	826.0	841.5	885.8	930.8	951.8



Appendices



NREL Organization Chart



Acronyms and Abbreviations

A

AFDC	Alternative Fuels Data Center
AFV	alternative fuel vehicle
AID	Agency for International Development
AMFA	Alternative Fuels Motor Act
ASA	analytical service agreement
ASHRAE	American Society of Heating Refrigerating and Air-Conditioning Engineers, Inc.
a-Si:H	hydrogenated amorphous silicon
ATV	advanced technology vehicle

B

BA	budget authorization
BES	(Office of) Basic Energy Sciences
BIPV	building integrated photovoltaics
BTS	Building Technology, State and Community (Programs)

C

CIS	copper indium diselenide
CLI	construction line item
CRADA	cooperative research and development agreement
CSP	concentrating solar power

D

DNA	deoxyribonucleic acid
DDRD	director's discretionary research and development
DPP	Distributed Power Program
DOE	Department of Energy
DWOP	Denver West Office Park
DWRI	Denver West Realty, Inc.

E

EPAct	Energy Policy Act
EERE	Office of Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EREC	Energy Efficiency and Renewable Energy Clearinghouse
EREN	Energy Efficiency and Renewable Energy Network
ES&H	environment, safety, and health
ESPC	energy-saving performance contracts

F

FEMP	Federal Energy Management Program
FIMS	federal information management system
FSN	FEMP service network
FTE	full-time equivalent
FTLB	Field Test Laboratory Building
FU	Fuels Utilization (Program)
FY	fiscal year

G

GEF	Global Environmental Facility
GO	Golden Field Office
GPE	general plant equipment
GWe	gigawatt electric

H

HEV	hybrid electric vehicle
HTS	high-temperature superconductivity
HVAC	heating, ventilation, and air conditioning

I

IEEE	Institute of Electrical and Electronics Engineers
IOF	industries of the future
ISM	integrated safety management
IT	information technology

J

JSF	Joyce Street Facility

K

K	Kelvin
kW	kilowatt
kWh	kilowatt-hour

L

LIMS	laboratory information management system

M

MBTU	mega British thermal units
MW	megawatt

N

NASA	National Aeronautics and Space Administration
NGO	nongovernmental organization
NOx	nitrogen oxides
NCPV	National Center for Photovoltaics
NREL	National Renewable Energy Laboratory
NWTC	National Wind Technology Center

O

O&M	operation and maintenance
OEM	original equipment manufacturer
OIT	Office of Industrial Technologies
OPBM	Office of Planning and Budget Management
OPT	Office of Power Technologies
ORNL	Oak Ridge National Laboratory

P

PC	personal computer
PCAST	President's Council of Advisors on Science and Technology
PDU	process development unit
PURPA	Public Utilities Regulatory Policy Act
PV	photovoltaic

R

R&D	research and development
RD&D	research, development, and demonstration
RFETS	Rocky Flats Environmental Technology Site
ROM	read-only memory
RPV	replacement plant value
RSF	Research Support Facility

S

SC	Office of Science
SERF	Solar Energy Research Facility
SOP	standard operating procedure
SPI	Superconductivity Partnership Initiative
STM	South Table Mountain
SRRL	Solar Radiation Research Laboratory

T

TCAPP	Technology Cooperation Agreement Pilot Project

U

UCB	University of California at Berkeley
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
UV	ultraviolet

W

WFO	work for others
WindPACT	Wind Partnerships for Advanced Component Technology

X

XPS	X-ray photoelectron spectroscopy

Y

Y2K	year 2000

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