National Renewable Energy Laboratory

Institutional Plan 2001 - 2005

On the Cover:

New Horizons for NREL

The inset photos juxtaposed over the image of the Earth's horizon illustrate biomass as a global resource. This bioenergy theme celebrates the recent DOE announcement of the National Bioenergy Center to be located at NREL. Led jointly by NREL and Oak Ridge National Laboratory, the center will be home to world class bioenergy research and state-of-the-art laboratory facilities, and the focal point for technology development and information about bioenergy in the United States.

Photos (top to bottom):

A scanning tunneling micrograph shows the luminal surface of granal membrane fragments isolated from spinach, which are enriched in photosystem II water-splitting activity to produce ethanol from biomass.

Researcher Min Zhang viewing computer terminal display of DNA extracted from the metabolically engineered *Zymomonas mobilis*, used to ferment zylose and glucose for alcohol fuels.

At this fluidized bed reactor, NREL researchers can recycle carpets to recover plastic to make new plastic products.

The McNeil Generating Station is the country's first biomass gasifier, suppling clean, renewable fuel from biomass to a utility power plant.

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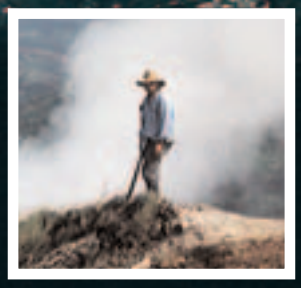


Director's Statement

Richard H. Truly

At the dawn of the 21st century, the United States faces major energy related challenges. Energy has again become front-page news for the first time in 25 years. During the first year of this new century, energy consumers in many regions of the nation were surprised by a considerable volatility in electricity, natural gas and gasoline prices. The western U.S. in particular experienced "out-of-control" energy market prices, electricity shortages, including rolling blackouts in California and, of late, critical financial problems for some utilities and customers in that state.

Indeed, a decade's neglect of investment in energy infrastructure has resulted in a national energy system that has become, in many cases, aged and stressed to the limit. At the same time, the energy marketplace is experiencing some dramatic consumer changes that are introducing additional demands. U.S. energy consumers have always demanded low-cost, reliable energy, but an increasingly competitive global marketplace has accentuated this need.

Lowest cost is not the only concern of the modern energy consumer. Rapidly growing sectors of businesses and homes are requiring unprecedented levels of electricity reliability and power quality, caused in part by a greater reliance on digital appliances and round-the-clock business practices.

Modern energy consumers are also increasingly concerned about the environmental health and safety effects of their energy supplies. There has been a consequential growth in demand for energy products like "green" power and sustainable energy resources to be used instead of the more traditional but "dirtier" or depletable resources.

These varied and often conflicting needs are creating consumers with a growing number of complex value propositions. Satisfying these needs comes with a price, but the modern energy consumer in some instances has already demonstrated a willingness to pay premiums. The result has been the emergence of a new breed of energy service provider who is looking for new energy products and services that go beyond offering simple energy commodities at lowest cost.

Most promising of these are services and products in the distributed energy area that are being developed to meet the needs of remote and high reliability energy markets. If current market and policy barriers are removed and certain new technologies developed, this new form of electric generation has the potential to radically alter the electric and natural gas industry structures. For the first time an electric generator can be offered as a product that can supply a wide variety of high-value energy services finely tuned to specific customer needs at specific locations.

Renewable energy and energy efficiency are poised to play a big role in providing these new energy products and services and to help address a number of our nation's pressing energy problems.

We faced an energy crisis of similar magnitude a quarter century ago. Back then the nation took a number of actions to address the energy problems of the moment, setting into motion some measures to protect against future energy problems of this magnitude.

Obviously, these measures weren't entirely successful, in part because the national concern over energy died down—people lost interest, relaxed their vigil and reduced their support.

One of the measures taken roughly 25 years ago was based on the concept of sustainability. The premise was that energy efficiency and renewable energy held the promise of an unlimited supply of affordable, clean, reliable and secure energy. The expectations were high and the realization seemed near, but today this promise has only materialized for relatively few people.

Looking back to the last national energy crisis, perhaps we were simply witnessing the birth of sustainability. Expectations were overly optimistic for the rate at which energy efficiency and renewable energy solutions would arrive. We should have known better. It has always taken many decades for technologies to develop, markets to grow, and for policies to evolve for any new kind of energy to blossom.

But energy efficiency and renewable energy technologies, markets and policies have been maturing. Technology costs have been steadily declining, sales in many instances have been growing at double digit rates, and a number of policies have been, or are being, implemented that should smooth the pathway for a new energy platform based on sustainability. One of the key messages coming from this latest national energy conversation is that energy efficiency and renewable energy might now be at their coming out stage, ready to make an increasingly meaningful contribution to our energy mix.

Our energy challenges go beyond our national boundaries. Uninterrupted energy supplies are crucial to national security, economic health and continued U.S. leadership in highly competitive world markets. America now depends on other nations for more than half its oil, and the emissions resulting from a fossil-fuel-based energy economy continue to raise concerns about near—and long-term effects.

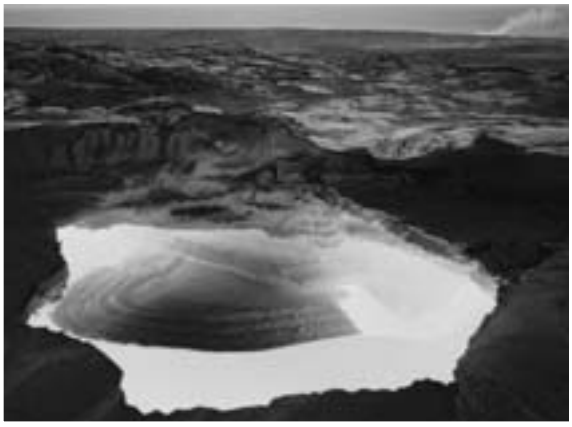
Population growth and economic development in Asia, Africa, and Latin America have combined to lead a rapid expansion of global energy demand. Today's developing nations, with nearly 80 percent of the world's population, account for only a third of all energy use, but their electricity growth rate is 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 pose enormous pressures on energy infrastructure and on the global environment.

Energy security and environmental impact will be important drivers at home and abroad. 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.

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.

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 never-ending supplies of energy will not be realized. Without a commitment to develop the technologies that allow us to use less energy while still meeting our needs, we will continue to demand more and more. And without a commitment to make those technologies available to the market at competitive costs and in highly reliable systems, their benefits to the energy security, the economy, and the environment will not be realized.

Pursuing clean energy technology development is the National Renewable Energy Laboratory's (NREL) mission. As the nation's premier institution for renewable



"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 never-ending supplies of energy will not be realized."

—Richard H. Truly

energy and a leader in energy efficiency, NREL supports the U.S. Department of Energy (DOE) by working in partnership with other laboratories, universities, industry, utilities, independent power producers, and other energy market players to help our nation provide for the energy needs of the future.

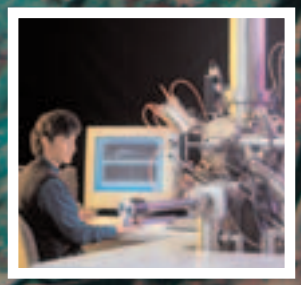
In this new century, NREL will continue to seek the most efficient and cost-effective energy technologies and assist DOE and U.S. industry in their development. Our core technology development in photovoltaics, wind energy, and bioenergy will continue. We will also support DOE research and development to advance hydrogen, concentrating solar power, solar heat and building energy, geothermal, fuels utilization, related industrial technologies, and advanced automotive technologies. We will continue to place particular emphasis on efforts to improve the efficiency of and use of clean energy resources by the federal government, and on crosscutting efforts to provide analysis and technical information. Over the coming decades, our clean energy contributions will have increasingly visible impacts in all energy sectors, from cleaner and healthier buildings and less oil-dependent transportation to renewable feedstocks for industry and more efficient energy and electric power generation and use.

We are responding to new opportunities and needs with a focus 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 focus 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 use renewables in hybrid energy generating systems, bringing them closer to the end user. Basic scientific research remains 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 with a particular focus on biosciences, nanoscience, and computational science 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



NREL is a leader in DOE's effort to secure an energy future for the nation that is environmentally and economically sustainable. 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, and advancing 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. 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 94 percent of NREL's funded activities have been in support of two DOE offices — the Office of Energy Efficiency and Renewable Energy (EERE) and the Office of Science (SC). This trend continued in FY 2000 (Figure 1).

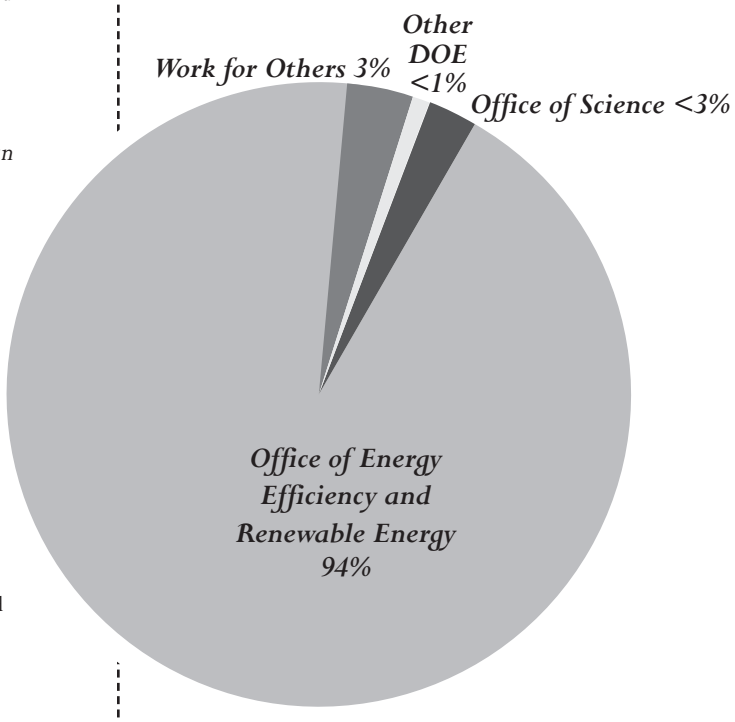
Mission

Vision

Core Competencies

Partnerships and Collaborations

Performance Management



NREL's FY 2000 Funded Activities

Figure 1. Keeping relatively consistent with historical trends in FY 2000, about 94 percent of NREL's work was performed in support of DOE, with most of that work done for the Office of Energy Efficiency and Renewable Energy.

Mission

Office of Energy Efficiency and Renewable Energy

NREL conducts 94 percent of its work for EERE, supporting EERE's mission to develop advanced energy efficiency and clean power technologies and practices, in all four economic sectors (power, transportation, buildings, and industry) and in support of the Federal Energy Management Program and crosscutting activities under the Office of Planning, Budget, and Management. NREL's work for EERE is described in detail in the Science & Technology section, page 25.

Office of Science

DOE is the third largest government sponsor of basic research in the United States, primarily through programs managed by the Office of Science (SC). The research programs sponsored by SC 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 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.

Arms Control and Nonproliferation

NREL also supports 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 is consistent with its mission, NREL also does work with, and for, a wide range of parties outside of DOE, including:

- Industry, universities, state and local governments, and foreign entities
- Other U.S. federal government agencies
- Non-governmental organizations.

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 2000, NREL's work for others was three percent.

Mission

NREL develops renewable energy and energy efficiency technologies and practices, advances related science and engineering, and transfers knowledge and innovations to address the nation's energy and environmental goals.

Vision

NREL'S VISION FOR THE FUTURE IS A WORLD IN WHICH:

Access to energy resources and their consumption does not degrade the environment.

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 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, as shown in Figure 2. We are not alone in this view. Increasing numbers of U.S. and multinational companies are making major investments in clean energy 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 purchase "green energy" through utilities. There is an excellent opportunity emerging for advancing

The vision of earth as an integrated system is made very clear in photography taken by Space Shuttle astronauts. This photo was taken during a mission in May, 2000.

renewable energy and energy efficiency, both within the U.S. and internationally. 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 to 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 fuel source 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 sustain an expanding economy with an aging energy infrastructure, while meeting increasing demands for higher reliability driven in large measure by the emergence of a digital economy. With petroleum imports now surpassing the 50 percent mark — more than was imported during the oil crises of the 1970s — the nation is at ever-greater risk of disruption of, or price instability of, vital fuel supplies for transportation.

Progress toward NREL's vision will reduce the risk of price instability or energy supply disruption. The march toward a sustainable energy future will be engendered by the use of natural gas, which will serve as a bridge fuel as energy efficiency and renewable energy technologies continue to advance. Recent increases in natural gas prices and demand will continue to influence the utility of natural gas for electricity production. Ultimately, we will move toward a hydrogen economy.

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 initially penetrate the energy infrastructure through specialty markets. Eventually they will penetrate major new and emerging 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.

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.

EERE Technologies are Expected to Narrow the Energy Gap

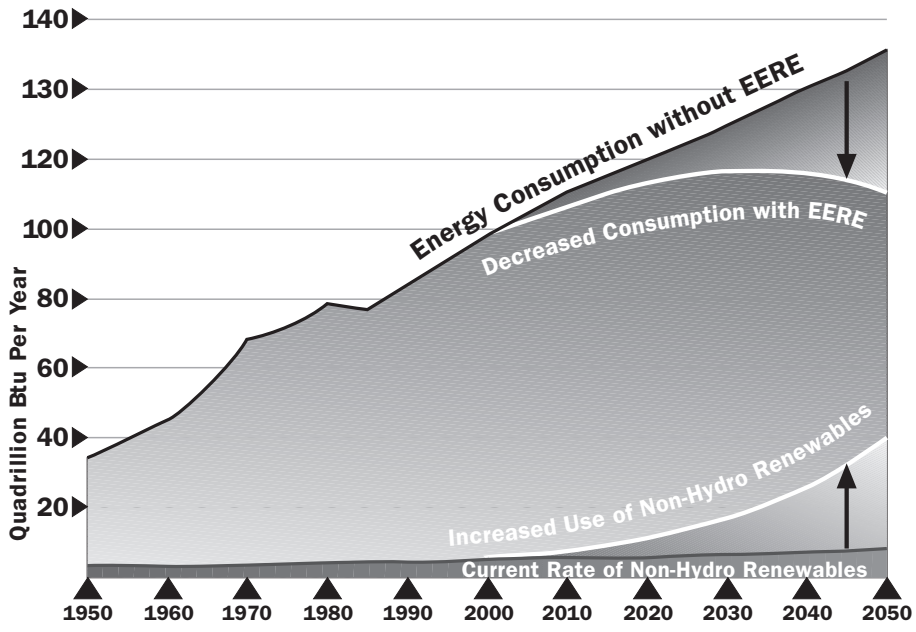
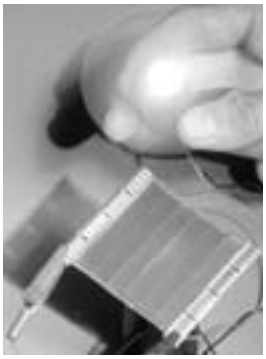


Figure 2. The gap between energy consumption and energy supply can be narrowed by both decreasing energy consumption through energy efficiency technologies and increasing the use of renewable energy technologies.

Core Competencies

CORE COMPETENCIES ARE THE FUNDAMENTAL TECHNICAL FOUNDATION from which scientific solutions to energy needs and sustainability are created, defining the national resource of expertise and capabilities that are available at NREL to DOE and NREL's other sponsors and customers.

While NREL's technical core competencies combine capabilities in scientific disciplines, such as chemistry and engineering, they are focused on development and characterization of renewable energy and energy efficiency technologies and waste conversion processes. The core competencies encompass all the interdependent steps in technology evolution: basic research, applied research, engineering development, manufacturing technologies, market assessment and conditioning, and facilitating commercialization.



This photoelectrochemical solar cell produces electricity through a chemical reaction in response to sunlight.

NREL's core competencies applied to renewable energy and energy efficiency technologies are:

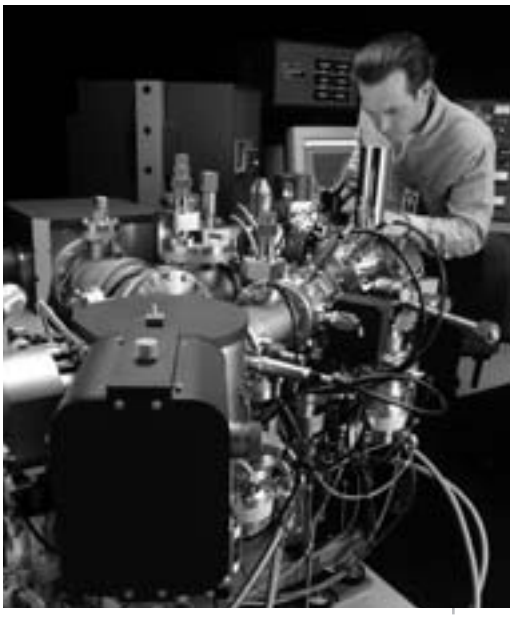
Basic Energy Science —
underlying energy conversion for renewable energy and energy efficiency applications. NREL physicists, chemists, and engineers are experts on the science of renewables-based energy conversion. Examples are biomass and waste conversion to chemicals, materials, power, and fuels; photoconversion; photobiological and electrochemical conversion; electrocatalysis, solid state theory; quantum mechanical modeling; novel compounds; and nanostructures.

Renewable Energy and Energy Efficiency Technology Development —
including photovoltaics (solar electric cells) and other solar electric generation; wind energy; bioscience and biotechnology for power, fuels, materials and fuels; building energy technologies; advanced fuels and vehicles; geothermal; solar thermal; and hydrogen. NREL scientists and engineers are experts at developing new concepts, materials, devices, and systems for all of the renewable energy and energy efficiency technologies.

Renewable Energy and Energy Efficiency Systems, Simulation, and Modeling, and Integration —
including distributed power and hybrid systems, and assessment of the renewable resources. NREL researchers are experts in integrating energy devices into systems that provide energy services. Examples are distributed energy modeling, simulation, and testing; building energy modeling such as Energy-10; advanced vehicle models such as ADVISOR; advanced fuel cell technologies; biofuels process engineering, process integration, scale up, and demonstration; and life-cycle analysis.

Advanced Measurements, Characterization, and Analytical Techniques —
in support of technology development. NREL has exceptional capabilities in measurements, characterization, and analytical techniques to support the development of theories and hypotheses, and to test prototype materials, concepts, devices and systems with advanced methods and tools. Examples are solid state spectroscopy; photovoltaic device measurements, characterization, performance, and reliability testing; and turbine blade stress testing and modeling.

Energy Policy Analysis and Decision Support—
related to the adoption of renewable energy and energy efficiency technologies, such as green marketing concepts. NREL's analysis staff are experts in analyzing renewable energy policy, markets, and technologies; creating and analyzing mechanisms to overcome barriers to the use of renewable energy and energy efficiency technologies; and providing technical information and support to stakeholders. Examples include leadership in green-electricity market analysis; technical support to federal facility energy managers in identifying, assessing, and implementing cost-effective clean energy projects; and conducting field tests on the performance of alternative fuels and vehicles and making the results available electronically to stakeholders.



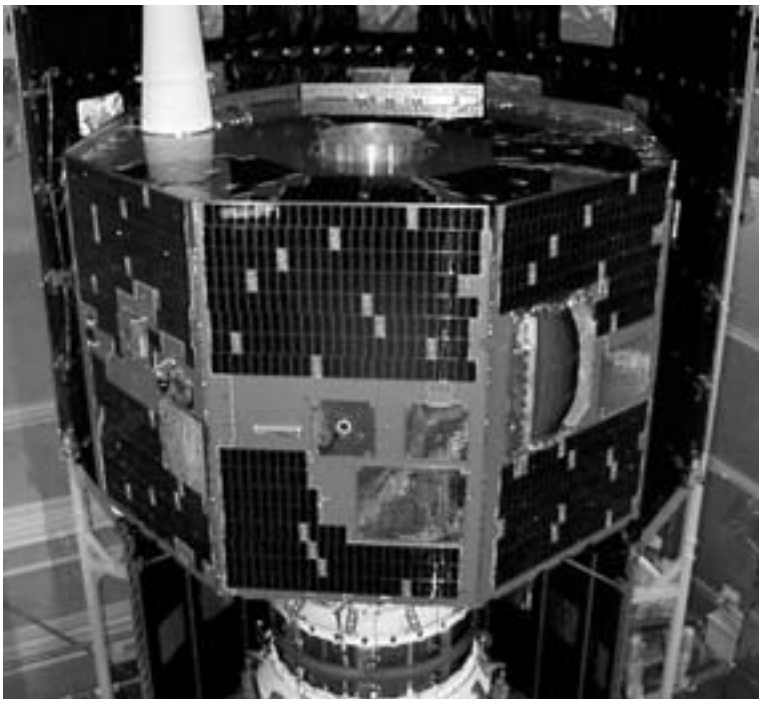
NREL researcher works at a secondary ion mass spectrometer to diagnose solid-state surfaces and interfaces.

NREL researchers perform dynamometer testing on Honda's Insight hybrid electric vehicle at the Environmental Test Chamber.

Partnerships and Collaborations

Partnerships are critically important at NREL. The Laboratory has been building a foundation of partnerships since its inception, integrating 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 issues are often difficult and complex. NREL applies its technical expertise 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 and implementation.

In any given year approximately half of NREL's funding returns directly to the private sector through subcontracts, cost-shared research agreements and procurements. Research partners include more than 70 universities, 250 companies, 25 state energy offices and 80 not-for-profit organizations. Small businesses have always been a special focus for NREL procurement practices. NREL's progressive business practices have been honored by the Small Business Administration, Minority Enterprises, Inc., and the Federal Laboratory Consortium.



Using new solid-state technology pioneered by NREL researchers, SpectroLab, with help from NREL, built a photovoltaic system to power the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) satellite. The satellite was launched by NASA in March 2000 to study the Earth's magnetosphere and related phenomena, such as the aurora borealis.

Performance Management

NREL'S INTEGRATED PLANNING AND PERFORMANCE ASSESSMENT PROCESS is well established and represents the continuum of activities from strategic planning and budgeting through performance assessment. This process promotes integration across programs and organizations, alignment of NREL and DOE strategy and plans, captures and considers market and stakeholder input, and fosters accountability for outcomes through performance assessment, as shown in Figure 3.

The Laboratory's Institutional Plan articulates the strategic foundation and long-term direction, as well as the highest-level, long-term outcomes expected from the laboratory (e.g. Critical Outcomes). The plan is developed and updated in consultation with DOE and other stakeholders.

NREL's One-Year Plan represents an annual "slice" of the Institutional Plan and translates strategy into nearer-term actions that will move the Laboratory closer to achieving its vision during the current year. The One-Year Plan provides the framework for annual program and organizational planning, serves as the basis for resource allocation, and outlines how the performance of the Laboratory will be evaluated for the two performance periods with each fiscal year. The One-Year Plan defines specific Performance Objectives to be achieved within each Critical Outcome category, the Key Tasks that will be undertaken achieve them, and the Performance Indicators that will be used as the evidence of progress. More details covering approach, staffing and budgeting, milestones, and schedule are provided in the annual operating plans for each individual NREL program, strategic initiative, office, and center.

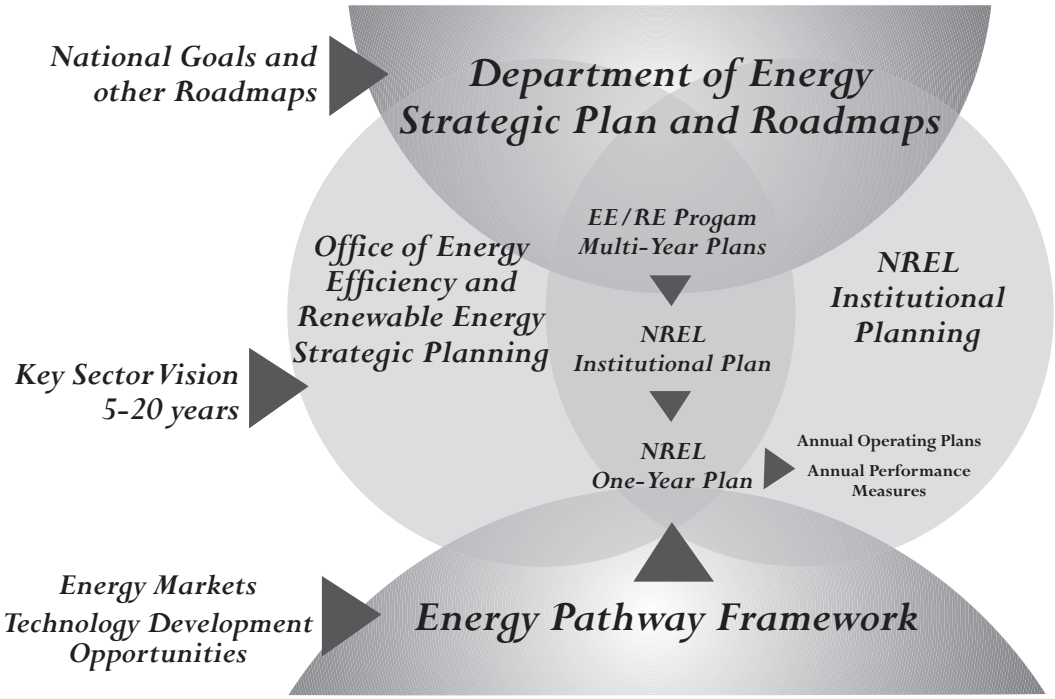


Figure 3.
An Integrated Planning and Assessment Process
NREL planning derives from DOE strategic directions and the trends and influences in the energy marketplace, ensuring that activities on an annual basis at the Laboratory do indeed respond to national needs.

This sophisticated measurement tool developed at NREL brings the laboratory to the power plant. The Transportable Molecular Beam Mass Spectrometer measures elements of the hot-gas stream that cannot be seen with gas chromatography. Analysis of the gas stream helps evaluate cleanup systems at power plants.

DOE and NREL have established six Critical Outcomes for the Laboratory: 1) Science and Technology; 2) Leadership; 3) Laboratory Viability; 4) Mission Support; 5) Environment, Safety & Health; and 6) Outreach and Stakeholder Relations. The six Critical Outcomes are summarized below, along with the general strategy for achieving each over the long term. The associated Performance Objectives for each Critical Outcome are expected to be accomplished during the five-year planning period. Critical Outcomes cut across NREL organizational management structures, yet reflect the five-year functional views expressed in related parts of this Institutional Plan. Determining the strategies and performance objectives, and executing the key tasks for each Critical Outcome, are the responsibility of the NREL management team.

Science and Technology

Conduct energy research, development, field verification and testing, and technical analysis and assistance efforts that advance viable energy technology options, that span energy pathways from supply through conversion and delivery to end-use applications, from concept to application.

Moving renewable energy and energy efficiency technologies from concept to commercial adoption is the core of NREL's mission. This critical outcome captures the results the Laboratory produces through the programs it conducts for DOE. NREL will continue to develop its portfolio of programs and program plans to meet the national goals outlined in the most recent DOE Strategic Plan and EERE Strategic Plan. These national goals require execution of a balanced set of activities, encompassing all the elements of technology development from concept to commercial application. Fundamental research and technology development will continue to be the major focus of NREL's efforts. Increasing emphasis will be placed on integrating renewable energy technologies and integrating renewables with fossil fuels, including cross-sector synergies.

We will continue to emphasize world-class scientific quality, using internal and external peer reviews and external recognition as the arbiter of quality. To be most effective in achieving its mission, NREL will lead or support the preparation of market-informed, long-range technology development plans (roadmaps) and measure progress against those roadmaps, and will continue to emphasize the importance of transferring NREL technologies to the marketplace.

Specifically, NREL will:

- Produce high-quality, externally recognized scientific research and development results
- Demonstrate leadership in planning, managing, and communicating about programs to deliver key technical outcomes
- Enhance the effectiveness of NREL's technology transfer and demonstrate stewardship of NREL's intellectual property
- Conduct new programs that will integrate renewables with fossil fuels, develop new technologies that integrate across specific economic sectors, and/or more effectively achieve national energy goals
- Assist in the preparation, or revision, of technology development roadmaps for all major NREL technologies
- Assess and develop plans to minimize the life-cycle environmental impacts of all NREL technologies.

Leadership

Provide leadership to promote NREL's national and international standing, ensure intellectual excellence and foster responsible stewardship of the DOE resource.

The Laboratory will continue to pursue opportunities for further involving key stakeholders representing energy markets, policymakers, environmental groups, and others in developing strategic directions for the Laboratory. The ultimate goal of involving stakeholders is to further the NREL and DOE missions as well as to create or identify opportunities to work with non-DOE customers more effectively. A key component of NREL's leadership is to identify the potential future roles and benefits of clean energy technologies in domestic and global energy markets. NREL will use its collaborative technology and applications analysis, energy market analysis, and program and policy analysis efforts to provide that understanding as well as to guide technology and to support policy formulation. The Laboratory will exploit opportunities for new and expanded programs to support the DOE and NREL mission, building on core competencies and technical opportunities, and selecting program areas that respond to the most urgent national needs.

Specifically, NREL intends to:

- Demonstrate leadership in developing new or enhanced programs that support the EERE mission and further national goals, including integration of renewable energy technologies across sectors and with fossil fuels
- Enhance the standing of NREL in the national and international communities through leadership of, and participation in, mission-related national and inter-national forums
- Demonstrate the Laboratory's commitment to its mission in its own operations by enhancing NREL's infrastructure and operating practices to maximize efficient use of resources, increase the use of renewable resources, and minimize negative impacts on the environment
- Catalyze the availability of private sector financial resources for clean energy ventures by expanding the network of EERE technology incubator alliances with private sector business incubators
- Analyze impacts of potential domestic and international policies on future energy use, and offer suggestions as warranted.
- Strengthen partnerships with key energy users and stakeholders within state, federal, and international agencies
- Maintain the active participation and effective use of a Laboratory advisory council made up of experts of national or international stature from academia, industry, and government.

Laboratory Viability

Ensure the long-term viability of NREL through enhancement of institutional visibility and ensuring retention of core scientific and business competencies and facility capabilities.

Laboratory viability depends on core technical competencies, including excellence in research staff, facilities and equipment. Core technical competencies include not only the capabilities necessary to accomplish the specific research tasks of today and those anticipated for the next several years, but also the enabling competencies that benefit all programs. Enabling competencies include analysis, modeling, scientific computing, resource assessment, and technical communications, among others. We will continue to develop core technical competencies through strategic

The research being done by this Directors Discretionary R&D project — advanced plant biotechnology and genetic characterization — crosscuts two research centers at the Laboratory and builds capability to address multiple technology goals. The objective of this project is to apply chemical techniques to solve biological problems, and to establish a close working relationship with industry, academia, and government in plant technology.

hiring, strategic investments made via the Director's Discretionary R&D fund, program investments, and the development of collaborative relationships. We will also continue to develop core technical competencies through maintaining, and adding as necessary, laboratories, process development facilities, field test areas, research and general purpose equipment, and the overall campus at NREL sites.

Specifically, NREL intends to:

- Work with DOE stakeholders to ensure stewardship of DOE assets at NREL
- Work with DOE to identify and secure funding for the need for new and additional facilities and equipment to sustain NREL's current assets, support today's programs, and prepare the Laboratory for tomorrow's research directions
- Build and sustain the core technical competencies in research expertise and physical infrastructure necessary to accomplish the research tasks anticipated in the next several years in a manner that will achieve an appropriate balance among financial, environmental, and public responsibility considerations
- Develop expanded collaborations and partnerships to enhance NREL's analysis capabilities
- Improve the effectiveness and productivity of NREL's research efforts by improving and expanding NREL's capabilities in computational science
- Conduct a high-level (National Academy of Sciences) review of selected areas of NREL's core competencies and implement recommendations.

Mission Support

Design, enhance and implement NREL business and management systems and work processes to provide an effective and efficient work environment that enables execution of the mission.

Accomplishing NREL's mission requires effectiveness in all the Laboratory's management systems, and a supportive work environment to foster excellence in both research and operations. Excellence means not only cost-effective and streamlined processes, but also work processes that have a minimal impact on the environment and are sensitive to the welfare of staff and neighbors. Policies and procedures will support these goals, including emphasizing internal communication, staff diversity, innovation and teamwork, and staff development.

Specifically, NREL intends to:

- Identify and improve specific management and operational areas through a targeted laboratory improvement program, ensuring an appropriate balance among financial, environmental, and public responsibility considerations.
- Work with DOE to locate administrative staff into facilities that are the most effective both in terms of cost and laboratory management.
- Maintain investments in information architecture and infrastructure to support new initiatives such as computational science; ongoing research programs; steady improvements in business systems such as finance, telecommunications, and networks; and the increasing demand for information sharing, collaborations, and virtual laboratories.
- Improve financial performance through a rigorous and well-informed make-or-buy decision process, advance procurement planning, and effective management information systems.

- Increasingly implement electronic commerce procedures into procurement and financial operations.
- Improve staff development and retention through rewards and recognition, flexible work schedules, sabbatical opportunities, management development training, dual career tracks for technical experts, and other approaches.
- Ensure cost-effective protection for NREL personnel and DOE property using a risk-based approach.
- Conduct regular staff surveys, analyze results, and implement warranted improvements.

Environment, Safety and Health

Ensure that NREL protects the safety and health of the workforce and the community, and the environment.

NREL will ensure that the safety and health of the workforce, the community and the environment are protected. This will require maintaining effective management systems to identify and mitigate risks, implemented through NREL's integrated safety management (ISM) system. The Laboratory will continue appropriate ES&H organization staffing and activity funding, and ensure clear understanding of ES&H roles, responsibilities, and authorities for line managers and employees.

Specifically, NREL intends to:

- Sustain excellence in safety and health, and environmental protection through proactive and integrated management systems
- Expand benchmarking comparisons of NREL ES&H standards and performance with industry and other DOE sites
- Improve the effectiveness of the Risk Assessment and Environmental Management programs
- Complete an organizational efficiency analysis and implement findings.

Located at the Solar Energy Research Facility, these control panels monitor the potential release of toxic gases.

NREL Environment, Safety and Health employees perform site characterization studies at NREL to ensure that Laboratory activities do not adversely impact the environment.

Outreach and Stakeholder Relations

Provide leadership in building strong relationships and new alliances with local, regional, national and international stakeholders to advance awareness and support of the DOE renewable and energy efficiency mission and technologies, foster open communications, and advance math, science, and technology education.

Students from a science camp learn about solar energy at NREL's Outdoor Test Facility.

With energy usage and issues permeating the entire worldwide economy, it is imperative that the opportunities and progress in renewable energy and energy efficiency technologies be broadly understood by decision makers in the United States and abroad. It is equally imperative to the success of the Laboratory's mission — in terms of recruiting excellent staff, benefiting from stakeholder input and insights, and other needs—that NREL's accomplishments and capabilities be visible to stakeholders and the American public.

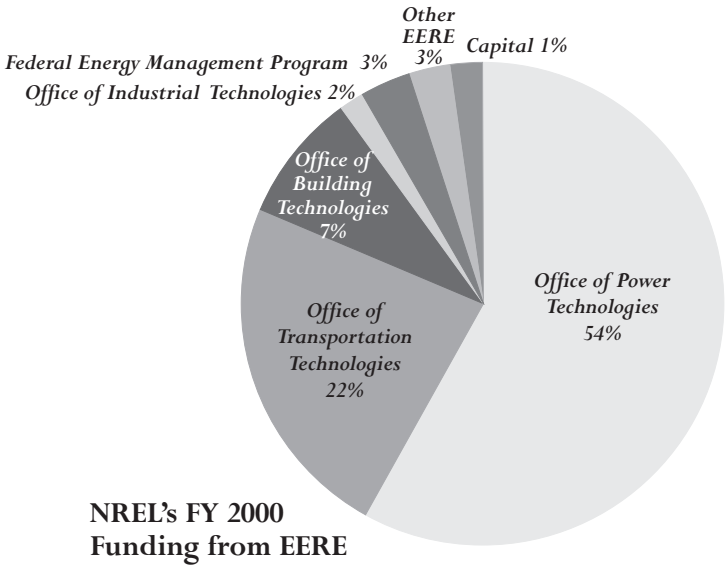
Specifically, NREL intends to:

- Improve NREL's ability to recruit world class staff and to attract valuable research and development partners by raising the national and international recognition of NREL's research accomplishments
- Enhance the ability of NREL to work most cooperatively and effectively with local officials, and enhance the standing of NREL as a corporate citizen in its local and regional setting, by increasing attendance at the NREL Visitors Center, involving more NREL leaders in key community organizations, and working with the local community to improve the environmental performance not only of NREL but of local organizations and companies
- Provide a national focal point for information on clean energy options by continuing to expand and improve the Energy Efficiency/Renewable Energy Network and Hotline
- Identify and implement advances in electronic publishing that will help to provide the information on renewable energy and energy efficiency advances needed by key EERE stakeholders
- Develop and conduct institutes for K-12 teachers on the science and technology fundamental to energy efficiency and renewable energy
- Raise awareness of EERE technologies and NREL research among minorities by establishing model partnerships for Historically Black Colleges and Universities, Native American and Hispanic institutions, and others
- Participate in national DOE research intern programs for K-12 teachers, community college and undergraduate students
- Ensure a stronger pool of future scientists and engineers knowledgeable about energy efficiency and renewable energy by establishing NREL as a strong and recognized leader in the state, regional, and national education network.

Science and Technology

NREL 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 (EERE) and the Office of Science (SC). EERE 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, Budget, and Management (OPBM), as shown in Figure 4.

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.



NREL's FY 2000 Funding from EERE

Figure 4. While most of NREL's FY 2000 funding from the Office of Energy Efficiency and Renewable Energy supported the power, transportation, and building sectors, they also assisted in important areas that address the energy issues of all economic sectors.

Office of Energy Efficiency and Renewable Energy

Office of Power Technologies
- Photovoltaics
- Wind Energy
- Biopower
- Concentrating Solar Power
- Solar Buildings
- Hydrogen
- Geothermal Energy
- Distributed Power
- Superconductivity
- Energy Analysis

Office of Transportation Technologies
- Biofuels
- Fuels Utilization
- Advanced Automotive Technologies

Office of Building Technology, State and Community Programs

Office of Industrial Technologies

Federal Energy Management Program

Office of Planning, Budget, and Management
- Energy Analysis
- Information and Outreach

Office of Science

Material Sciences

Chemical Sciences

Energy Biosciences

Integration of Basic and Applied Science

Office of Energy Efficiency and Renewable Energy

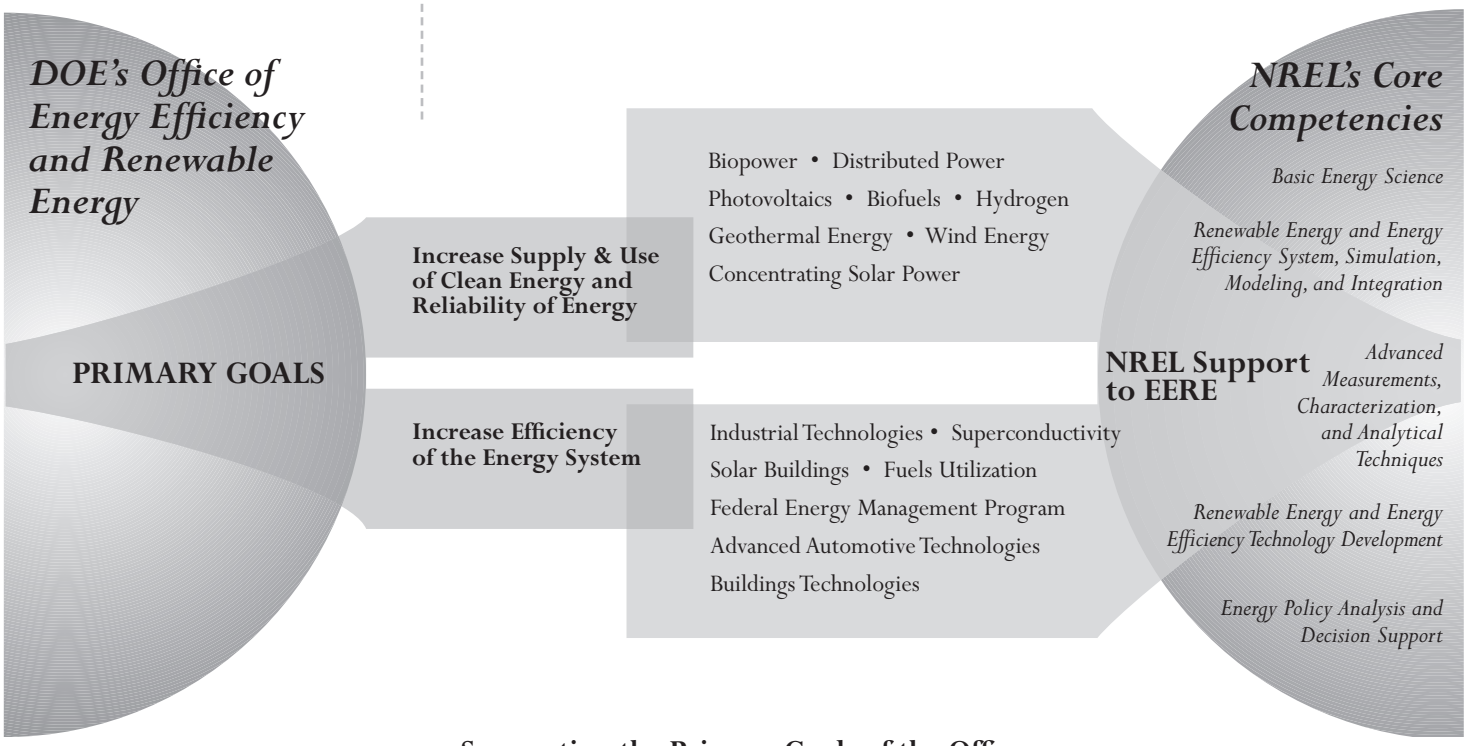
NREL conducts the great majority of its work for EERE, supporting EERE's mission to develop advanced energy efficiency and clean power technologies and practices. More specifically, NREL carries out more than a dozen DOE programs (Figure 5) employing its core capabilities to advance EERE's two stated energy-related strategic goals: 1) to increase the supply and use of clean energy resources and the reliability of the energy system; 2) to increase the efficiency of the energy system. 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 analyzes; and prepares and publishes information for both technical and non-technical audiences.

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 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 geothermal power plants
- **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

Science and Technology

- **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.



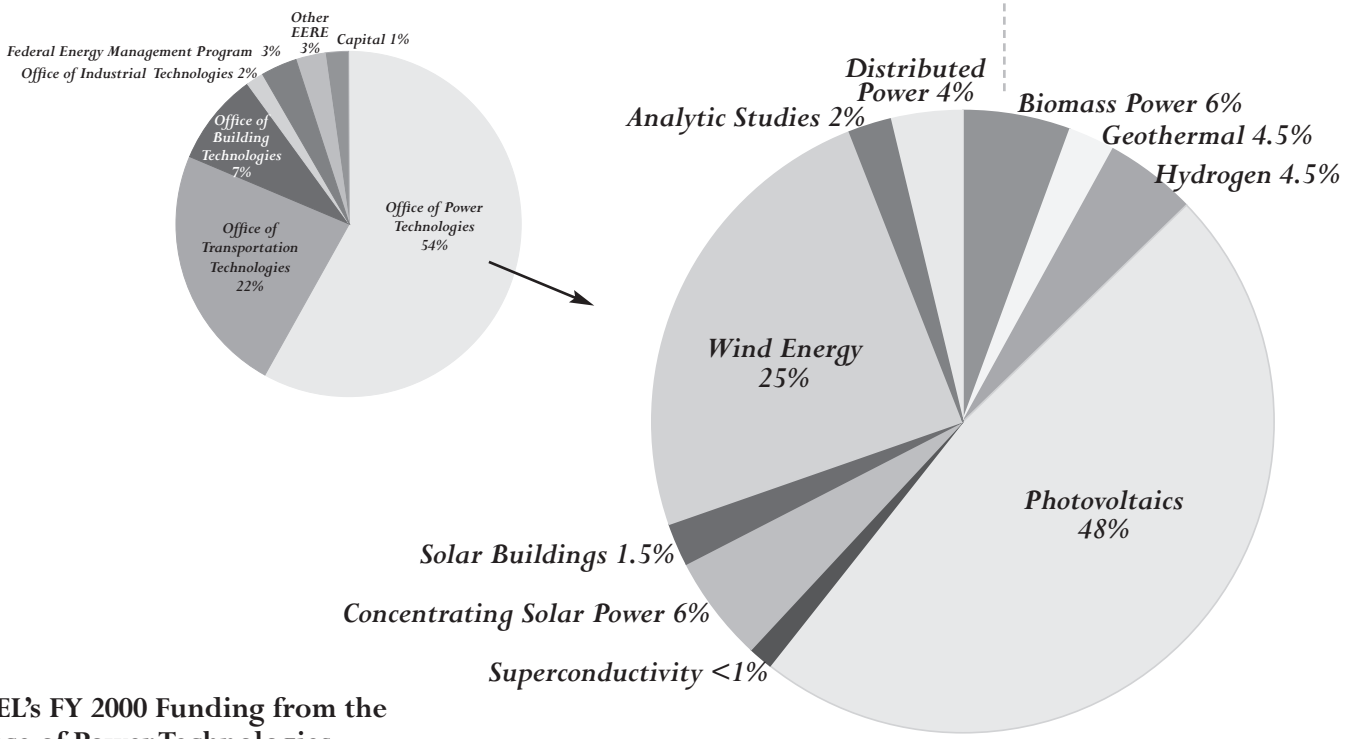
Supporting the Primary Goals of the Office of Energy Efficiency and Renewable Energy

Figure 5. 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.

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:

- Enhancing the use of renewable energy, tripling the installed U.S. capacity of non-hydroelectric renewables by 2010, and maintaining the viability of hydropower
- Enabling distributed energy resources to achieve 20 percent+ of new generation capacity by 2010
- Maintaining the present high reliability of the nation's electricity system
- Continuously improving OPT management and operations and enhancing our partnering capabilities.

NREL supports this mission by managing programs and projects and performing R&D in several program areas, as shown in Figure 6.



NREL's FY 2000 Funding from the Office of Power Technologies

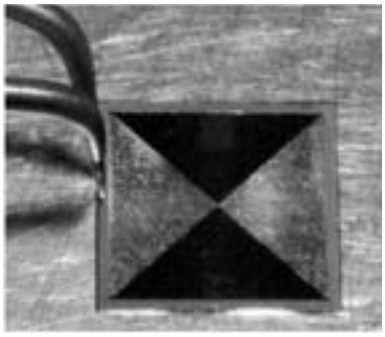
Figure 6. While most of NREL's FY 2000 funding from OPT supported photovoltaics and wind energy, all programs are critical to the future of U.S. power technologies.

Photovoltaics

The primary goal of the National Center for Photovoltaics (NCPV) is to help implement DOE's National Photovoltaics Program by encouraging the most efficient use of the nation's PV resources. The program receives 48 percent of OPT funding at NREL and exists to support the U.S. PV industry in improving the cost-effectiveness, performance, and reliability of its products (see Figure 6 on page 27 for program funding comparisons).

The NCPV is operated as "virtual laboratory" between NREL and Sandia National Laboratory, coordinating the PV activities between the two labs.

PV devices take advantage of the fact that the energy in sunlight 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 PV 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.



Grid pattern used for the 34% efficient triple junction solar cell. The strategy of this pattern with its L-shaped gridlines with optimized spacing is to maximize collection efficiency under concentration while optimizing exposure of the cell's surface to the incident solar flux.

Photovoltaic R&D is carried out through the NCPV, supporting DOE and the U.S. PV industry. The NCPV performs fundamental research into PV materials, semiconductor physics, and nanostructures; designs, develops, and tests PV cells in several material systems; characterizes and improves PV module performance and reliability; characterizes and improves the performance and reliability of PV systems; assists the industry with developing and implementing standardized tests and performance models for PV cells, modules, and systems; and works with the PV industry to accelerate the manufacturing capacity and commercialization of new and conventional PV technologies. 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.

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. Integration of PV into commercial and residential buildings is a major thrust worldwide. The U.S. PV industry shipped 61 megawatts of solar cells and modules in 1999, with sales growing more than 20 percent per year on average. The basic goal of the PV Program is to reduce the cost of PV technology so that it becomes economically competitive in distributed (grid-connected and stand-alone), value (premium power, remote, and consumer goods), and grid (wholesale) generation (central power and transmission/distribution support).

In-house R&D 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, selected through competitive solicitations. Ongoing R&D work with universities includes fundamental research and innovative, future generation PV technologies. In addition, universities and industry participate in the Thin Film PV Partnership. Important subcontracts supporting technology development include manufacturing R&D with industry partners. 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, such as commercial and residential buildings.

Two new initiatives were started in FY 2000. High-performance PV research 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 non-conventional, breakthrough technologies aimed at future, potentially very low cost approaches.

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 expanding

Accomplishments in Photovoltaics

Deposited amorphous silicon (a-Si) by hot-wire chemical vapor deposition (CVD) at rates greater than 0.5 microns/min (83 Å/s) with a stabilized defect density of 4×10^{16} cm^{-3}, a level comparable to the best low-rate a-Si used in production. Higher deposition rates would reduce the industry's up-front and total capital equipment costs and potentially reduce source materials costs.

Record efficiency for a cadmium telluride module (10.6 percent) achieved by industry partner (BP Solar), resulting in the company's decision to commercialize the technology.

Developed new conducting oxides, achieving 240 cm^2/Vs mobility in CdO grown using a metalorganic precursor. This could facilitate the use of cadmium stannate in commercial applications, such as at BP Solarex and First Solar. The switch to cadmium stannate could substantially boost module efficiencies relative to the tin oxide used today.

Established reproducible baseline processes for achieving solar cell efficiencies greater than 18 percent. This result not only provides an excellent platform for continued improvements toward the 20 percent-efficiency goal, but also serves a crucial support to industry. For example, Siemens Solar Industries used NREL's baseline processes for completing more than forty devices cut from modules to assist them in characterizing production uniformity.

Extended the operation of high-efficiency, triple-junction GaInP/ GaAs/Ge cells to 1100 suns concentration. Further, in partnership with SpectroLab, NCPV achieved a 32.2 percent efficiency at 660 suns with the cells, which is a record for any device above 200 suns concentration.

Significantly increased industry investments in thin-film technologies with several multi-megawatt manufacturing plants under development in amorphous silicon, CdTe, and CIS technologies.

NREL researcher uses the scanning Fourier transform infrared microscope to examine novel PV materials.

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 percent annual growth rate.

During the next five years, NCPV expects to:

- 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 percent-efficient a-Si cell and a 20 percent-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 percent-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 electrooptical-based diagnostic technique to the PV industry
- Demonstrate the achievement of voltage addition in a 4-junction device
- Demonstrate a 10 percent-efficient commercial CdTe module
- Complete capability to evaluate multijunction concentrator cells and modules to 1000X with ±3 percent uncertainty
- Implement new partnerships to address processes capable of $1/watt direct module manufacturing costs with gigawatt production capacity.

The Cost of Solar Electric PV Power is Dropping

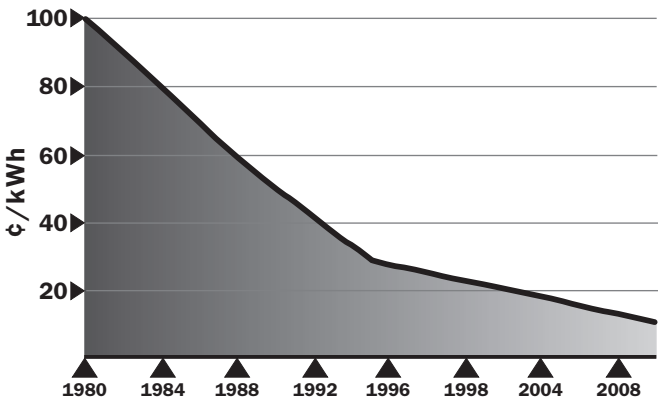


Figure 7. The cost of photovoltaic electricity has dropped from more than $1/kWh in 1980 to nearly 20¢/kWh today. With continued technological advances and with economics of scale, the cost will keep dropping.

Wind Energy

The mission of the DOE 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. The program receives 25 percent of OPT funding at NREL (see Figure 6 on page 27 for program funding comparisons). 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 with a high capacity blade test capability, 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 specifically 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 stall-regulated wind turbines by 23 percent to 35 percent.

The North Wind 100/20, which won an R&D 100 Award for the year 2000, is a state-of-the-art wind turbine that is ideal for extreme cold conditions and for remote locations that may be off-grid or local-grid.

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¢ 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 land (factoring in environmental and land use exclusions) and energetic winds to provide one-third of today's total U.S. electricity. Meeting the cost goals would also help America regain the lead in wind installations from Europe — which now has four 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

Accomplishments in Wind Energy

Established a joint operating program, with Underwriters Laboratories as an U.S. certification agent, facilitating sale of U.S. manufactured turbines in Europe.

Received R&D 100 Award for the development of a 100 kW Cold Weather Wind Turbine.

Received American Association for Laboratory Accreditation for the National Wind Technology Center for power performance, noise, power quality, loads, and blade static certification testing.

Installed and began testing the proof-of-concept machines for both of the next-generation turbine development subcontracts. Test results are being used to validate computer models created for each machine. The WTC turbine is under test at the NWTC, and the EW1.5 is being tested in Tehachapi. Both subcontractors recognize the invaluable support provided by the NWTC in keeping the tests on schedule, with high-quality data archives.

Completed the NASA Ames wind tunnel test as scheduled, providing an unprecedented data set of unsteady aerodynamic response. This data has been cataloged in a Web-based form that is currently being accessed by 30 different organizations around the world. A blind code comparison is being conducted that will allow the participants to compare their results from many different modeling techniques. New and innovative methods to predict unsteady aerodynamic performance are expected to result from this research that will allow airfoil and blade designers to build more efficient, cost effective blades.

Explored the causes of gearbox failures that are occurring in commercial applications using the dynamometer. The dynamometer is being used to simulate the drive train loading that is occurring from different braking schemes, as well as off-axis operation. Our industry partner, Enron Wind, is anxious to learn how to avoid costly repairs through control methods developed jointly with NREL staff and tested on the dynamometer.

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:

- Improve wind turbine aerodynamic, structural, and control system design tools
- 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 percent 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 program 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 closely coordinating with the DOE regional offices to conduct detailed resource assessment studies of high-potential states, working with FEMP

to aggregate federal loads and encourage the use of wind power for these loads, conducting workshops in high-priority regions of the country to encourage the use of wind power, and developing outreach materials and publications to educate stakeholders.

NREL has identified the need for upgrading its blade testing and dynamometer facilities to accommodate turbines greater than 2 MW. The Hybrid Power Test Bed, located at the NWTC, will be substantially upgraded and expanded to accommodate the research needs of the new Distributed Energy Program. A natural gas line will be installed in FY 2001, which will improve heating, ventilation, and air conditioning systems, as well as provide natural gas for research conducted at the Hybrid Power Test Bed.

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.

The Cost of Wind Energy is Dropping

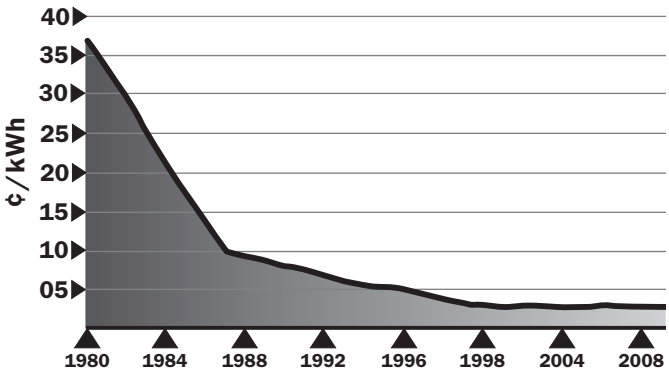


Figure 8. Since 1980 the costs of wind-generated electricity has dropped by more than eight-fold, to less than 5¢/kWh today. The goal of the Wind Energy Program is to bring costs down to 2.5¢/kWh.

Biopower

The objective of the DOE Biopower Program is to work with industry to expand the use of biomass for generating electricity and process heat. This program receives 6 percent of OPT funding at NREL (see Figure 6 on page 27 for program funding comparisons). Materials such as forestry industry residues, agricultural residues, the clean fraction of 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.

The McNeil generating station in Burlington, Vermont, is an innovative, high-throughput gasifier that converts biomass into gas for electric power generation. NREL provides analytical support to the facility.

Methane gas generated in landfills can also be captured and combusted. Unlike fossil fuels, biomass materials utilize atmospheric carbon dioxide in the growing process. The carbon dioxide released when they are converted to energy is balanced by carbon dioxide captured during their growth. Further, biomass residues used for power generation reduce landfill volume and avoid landfill methane emissions. Thus, the use of biomass for power generation represents a net reduction in greenhouse gas emissions. Biopower is 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 and 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, continued use of biomass will be dependent on realizing technological advances and cost reductions to make biopower more competitive with other power generating options.

NREL supports the DOE Biopower Program with research and development of thermochemical conversion technologies such as assessment and technical assistance for developing DOE-supported biopower projects. Specific current projects include work on small modular biopower systems for distributed generation, integrated biomass gasifier/generators, the chemistry of cofiring ash deposition, 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 demonstration efforts to most effectively advance the technology and will enhance its analysis, outreach and education efforts to further acceptance of biopower options.

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
- Investigate issues arising from integration of biomass gasification with microturbines and fuel cells
- Support DOE's new gasification development initiative
- Successfully support the parametric testing of the Vermont Gasifier
- Initiate efforts for advanced modeling for combustion and cofiring, dynamic simulation and process control, and feedstock production
- Support the Golden Field Office in completing two *Biomass Power for Rural Development* projects with more than 100 MW of new biomass power generating capacity
- 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.

Accomplishments in Biopower

Continued highly valued engineering and analysis support of the Vermont gasifier. Critical data was gathered during runs in the early spring to direct system modifications that have enabled substantial progress during the summer 2000-test runs including completion of initial parametric testing, process stability verification, demonstration of product consistency, operation at up to 150 percent of design throughput, demonstration of rapid gasifier startup and re-start and continuous operation in steam gasification mode for a total of well over one hundred hours.

Achieved record biomass throughput of 16 kg per hour during integrated testing of the NREL thermochemcial user facility (TCUF) with an internal combustion engine. These integrated runs have revealed key ranges operational parameters that affect emissions, power output, and engine wear and lifetime. Systems of the type being tested at NREL (gasifier/ engine) are the most widely used small biomass systems in the world.

Designed and constructed a laminar entrained-flow reactor and successfully operated it to extend the ash deposition and tar cracking testing beyond semi-batch operations. This type of reactor will permit development of thermodynamic equilibrium and kinetic models at the research scale that can directly be used for new and sophisticated modeling of PDU and commercial gasification and combustion systems.

Achieved long-duration operation of the Community Power Corp. (CPC) small system at and above its design power output. This system is being developed under NREL subcontract and in collaboration with Shell Renewables for use in the Philippines. NREL has provided significant support in design of the gasifier section and has applied the experience gained from our integrated TCUF testing to enable the developers to reach their goal.

Concentrating Solar Power

The DOE Concentrating Solar Power (CSP) Program leads the national effort to develop clean, competitive, and reliable power options using concentrated sunlight. Ranging in size from several kilowatts to multi-megawatt installations, CSP systems are expected to satisfy substantial domestic and international energy needs, contributing 20,000 MW by the year 2020. 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. 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 four new program technology paths: distributed power, dispatchable power, advanced components and systems, and alliances and markets. This program receives 6 percent of OPT funding at NREL (see Figure 6 on page 27 for program funding comparisons).

One of the technology pathways is represented by the Dish/Stirling system. The system uses dish concentrators to focus sunlight on a Stirling engine to drive a generator and produce electricity. This system is being tested at NREL's Mesa Top Test Facility.

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, working with industry to increase system reliability, and developing advanced components to reduce system cost.

NREL will assist DOE in focusing its CSP research efforts while continuing to work with Sandia National Laboratories through our SunLab collaboration. The SunLab collaboration advances the goals of the CSP Program by providing DOE and industry with integrated access to technical expertise and facilities needed to reduce the risk of (or overcome barriers to) developing and commercializing concentrating solar technology.

The Cost of Concentrating Solar Power is Dropping

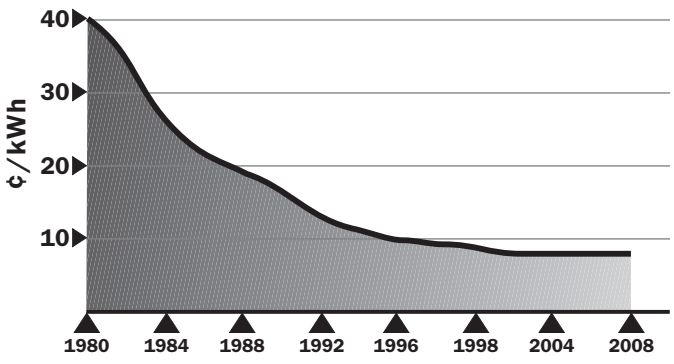


Figure 9. Since 1980 the costs of electricity generated with concentrated solar trough technology has fallen to nearly 10¢/kWh. With the expected advances in optical materials and concentrating systems, cost are expected to drop even more.

CPS 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.

Future use 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.

During the next five years, NREL expects to:

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

Accomplishments in Concentrating Solar Power

Continued promising development of durable, flexible "super-thin glass" reflective materials for concentrating solar power.

Established USA-Trough Program to develop world-class products and services for CSP.

Established collaborations with industry to develop and test designs for smaller remote and distributed power CSP applications.

Identified a potential breakthrough in the area of thermal storage through the use of "ionic liquids" that can create organic molten salts which can be liquid at 0∞C or below and are stable to above 400∞C. Early indications are that storage systems designed with these fluids may exceed the technical and economic goals established in the trough roadmap for the year 2010. A record of invention is in progress for this discovery.

Took over management of subcontracted efforts with Science Applications International Corporation (SAIC) to develop a 22 kW dish/Stirling system. The system has achieved new performance records, with one system reaching a weekly energy output of 477 kWh, or 87 percent of the theoretical maximum.

Developed a new optical analysis code, SOLTRACE, which significantly extends the state of the art for solar concentrator design. SOLTRACE provides researchers with the capability to analyze virtually any optical geometry using ray tracing, 3-dimensional data obtained by optically testing actual concentrators in the field, or data generated from finite element design codes. This new code allows NREL researchers to model and predict the performance of new, complex concentrator designs that previously could not be analyzed.

Solar Buildings

Established within OPT in FY 1997, the DOE Solar Buildings Technologies Program has a mission to advance the development and widespread use 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. This program receives one-and-a-half percent of OPT funding at NREL (see Figure 6 on page 27 for program funding comparisons).

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 2001 budget is allocated to subcontracted research and about one-third to NREL in-house research. NREL's current in-house activities are directed primarily toward a goal of cutting the cost of delivered energy in half by FY 2003 for solar hot water systems. Achieving this 50 percent cost reduction goal would not only increase the market share of solar water heaters (reducing energy cost and consumption), but would strongly position the U.S. solar industry in rapidly growing solar markets overseas. 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.

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
- Partner with U.S. homebuilders to build marketable prototypes and pilot projects of "zero energy" homes in various climates
- Work with solar industry partners to develop and test field-scale prototypes of the "next generation" of solar systems for water and space heating
- 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.

Accomplishments in Solar Buildings

Worked with five industry and research teams to develop solar water heating systems that would decrease costs by 50 percent. Key highlights of this research include:
• Proof of principle was established for using polymers in solar water heating systems that were traditionally made of metal and glass
• Proof of concept was established for two innovative designs that have potential to cut delivered energy cost of today's solar systems in half. Achieving this 50 percent cost reduction goal would not only increase the market share of solar water heaters (reducing energy cost and consumption), but would strongly position the U.S. solar industry in rapidly growing solar markets overseas.

The National Park Service and NREL worked together to create the new Zion National Park Visitor Center. This Trombe wall provides most of the heating for the building by trapping sun between a pane of glass and a black selective coating — a masonry wall stores the heat for later release into the building.

Hydrogen

The DOE Hydrogen Program conducts research and engineering development in the areas of hydrogen production, storage, and utilization, for the purpose of making hydrogen a cost-effective energy carrier for utility, buildings, and transportation applications. This program receives four-and-a-half percent of OPT funding at NREL (see Figure 6 on page 27 for program funding comparisons).

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. Through this R&D, NREL supports and fosters the transition to a hydrogen-based economy.

Hydrogen is the most plentiful element in the universe — this makes it an 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 storing, sensing, and using hydrogen.

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 provide timely, accurate, insightful, and forward-thinking analyses 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.

This semiconductor immersed into an aqueous solution has been the most efficient so far at splitting water into hydrogen and oxygen using sunlight.

Accomplishments in Hydrogen

Reached an in-principle agreement to licensed 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 (LCA) of the steam methane reforming process; this will serve as a base case for analysis of renewable energy technologies for producing hydrogen.

Completed detailed LCA of wind-electrolysis system and an analysis of coal-to-hydrogen systems with sequestration.

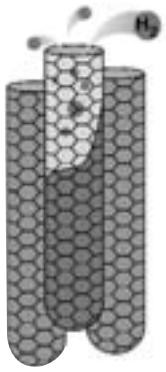
Demonstrated the thermal dissociation of methane to carbon black and hydrogen in a solar-thermal aerosol flow reactor system

Discovered a hydrogen-producing cyclic photobiological algal system, receiving extensive coverage in the scientific and popular press. An automated system to collect data from the synchronized cells under sulfur-deprived conditions was developed to increase the amount and accuracy of detailed information on the system.

Developed an automated (unattended) system that allows extended operation of the biomass-to-hydrogen steam reforming process. Ninety hours of operation without interruption provided extensive data on the lifetime of the catalyst and the operation of the system, important for the planned scale up of the project in conjunction with Clark Atlanta University.

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 percent oxygen for 10 minutes
- Develop 5 percent efficient nitridebased materials for photoelectrochemical water splitting
- Store hydrogen at 6 wt percent and room temperature in a system based on carbon nanotubes
- Construct and operate a microbial water-gas shift pilot plant
- Evaluate the commercial promise of a cyclic algal hydrogen production system
- Perform detailed life-cycle assessments of hydrogen production systems
- Develop and enhance hydrogen investment strategy
- Develop the necessary codes and standards for the introduction of hydrogen technologies.



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

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. The program has established the following goals:

- Supply the electrical power or heat energy needs of 5 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.

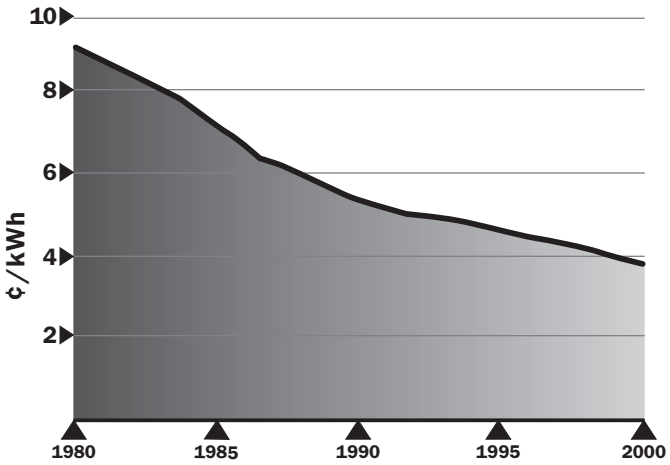
NREL contributes to these goals by improving the efficiency of heat transfer of geothermal technologies, by serving as a core laboratory for energy systems research and testing (including advanced plant systems) and through communication and outreach activities and analysis of economic issues. This program receives four-and-a-half percent of OPT funding at NREL (see Figure 6 on page 27 for program funding comparisons).

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 and for direct heat applications—all on a clean, reliable, and sustainable basis. 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.

During the next five years, NREL intends to expand its geothermal research collaborations with other DOE laboratories and industry 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
- Verify performance and economics of small-scale geothermal electricity plants.



The Cost of Geothermal Energy is Dropping

Figure 10. The cost of geothermal electricity has decreased by more than 50% since 1980 — to about 4¢/kWh.

Accomplishments in Geothermal Energy

Confirmed, through testing, the performance of new air-cooled condenser technology that improves efficiency by 30 percent for binary-cycle geothermal plants; patent application is in progress and industrial partners are being sought to complete the development and to commercialize the product.

Initiated, in conjunction with Brookhaven National Laboratory and several industrial partners, field tests to define the actual performance advantages of heat exchanger tube linings to allow long-term use of low-cost carbon steel tubes.

Established partnerships with five industrial companies to build and determine the performance of innovative geothermal electricity generation plants with the intent of verifying performance and costs for small plants of about 1 MWe.

Received R&D 100 Award and Federal Lab Consortium Award for advanced direct contact condenser that improves production efficiency of geothermal power plants by 5 percent and has been licensed to private industry.

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. The program receives four percent of OPT funding at NREL (see Figure 6 on page 27 for program funding comparisons) and was created to address system integration issues and market barriers that may prohibit the widespread commercialization of distributed power technologies.

Initial efforts under the program have involved creating national technical interconnection standards, establishing a research and development program addressing system integration technologies, documenting regulatory and institutional market barriers, and working with industry and state and federal policymakers to remove barriers. NREL has been leading these research activities for DOE.

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 unnecessary barriers to these technologies. The creation of standardized

A 15-kilowatt photovoltaic system recently installed in Arlington, Virginia feeds clean energy into the utility grid that supplies electricity to the Pentagon. NREL engineers and Contracts and Business Services personnel coordinated the project. Ascension Technology Inc. installed the 60 SunSine AC photovoltaic modules, which were developed with NREL's assistance under the Photovoltaic Manufacturing Technology Program.

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 use of distributed power systems.

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

- Conduct research projects in system interconnection, reliability, and safety, as mandated by Congress
- Conduct the Nevada test site demonstration project for DPP
- Assess and develop standards and codes effecting distributed power utilization, siting, and cost
- Design and initiate distributed power system(s) model development and validation through systems analysis and field testing
- Conduct regional field testing of distributed power on radial grids at the distribution level
- Establish a distributed power testing laboratory.

This house in coastal Maine generates its own electricity from a 4.25 kW PV system. Through a net-metering relationship with Central Maine Power, surplus solar electricity is exported to the utility grid, effectively spinning the utility meter backward. The owners get this power back in an even exchange at night, and during periods of low sun.

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.

After the discovery of high-temperature superconductivity (HTS) in 1986, industry around the world quickly recognized the enormous potential of this new technology. U.S., Japanese, and European researchers began a challenging, high-stakes race to apply HTS technology. To help U.S. industry develop HTS technology, 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 DOE's national laboratories.

An NREL customized chamber demonstrated a pulsed laser deposition system where extremely high quality films of HTS are created.

Program activities are organized into three categories: basic research in wire and systems technologies, and applied research. Researchers in wire technology are developing HTS wire capable of carrying large currents in magnetic fields. Researchers, including industry partners, in systems technology are developing long-length wires and prototype components that will be integrated into complete systems. Applied research is supported through the Superconductivity Partnership Initiative (SPI) and other device-specific projects.

This electrodeposition apparatus is used to produce superconductive coatings.

The primary focus of 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 promising magnetic properties at 77 K.

In the late 1980s, 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 Los Alamos National Laboratory and with several 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 five 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 compounds 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. The Laboratory will continue to provide technical support for DOE's SPI and help DOE monitor these 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. It is expected that the 10kWh flywheel energy storage device under development by Boeing, as part of the SPI program, will be integrated with a wind generator in 2001. This test will be carried out at the National Wind Technology Center.

Accomplishments in Superconductivity

Studied the HTS Tl films as an alternative to the mainstream "coated conductor" program on $YBa_2Cu_3O_{7-8}$. This effort consists of two key activities: electrodeposition processing to implement growth of "thick" biaxially textured Tl-oxide films and development of a heat treatment method that could be scaled to long lengths of conductor on a flexible metallic substrate. The demonstration of a biaxially textured Tl-oxide film on a textured metallic substrate, with high transport properties at useful magnetic fields, is the primary objective for the program.

Demonstrated high quality "epitaxial" Tl films produced by high-rate processing techniques such as electrodeposition and spray pyrolyis that should prove highly valuable for fabricating wire and tape suitable for electric power applications.

Electrodeposited Tl films demonstrate promising current density as a function of thickness which will allow higher transport currents to be achieved in a coated conductor. Earlier work has demonstrated Tl-films can easily be produced with attractive current density out to 10 microns.

Achieved a MA/cm^2 density with bismuth, lead and strontium doping using electrodeposition Tl films.

Demonstrated reproducible growth of a suitable ceramic oxide buffer configuration on textured metallic substrates such as nickel and nickel alloy.

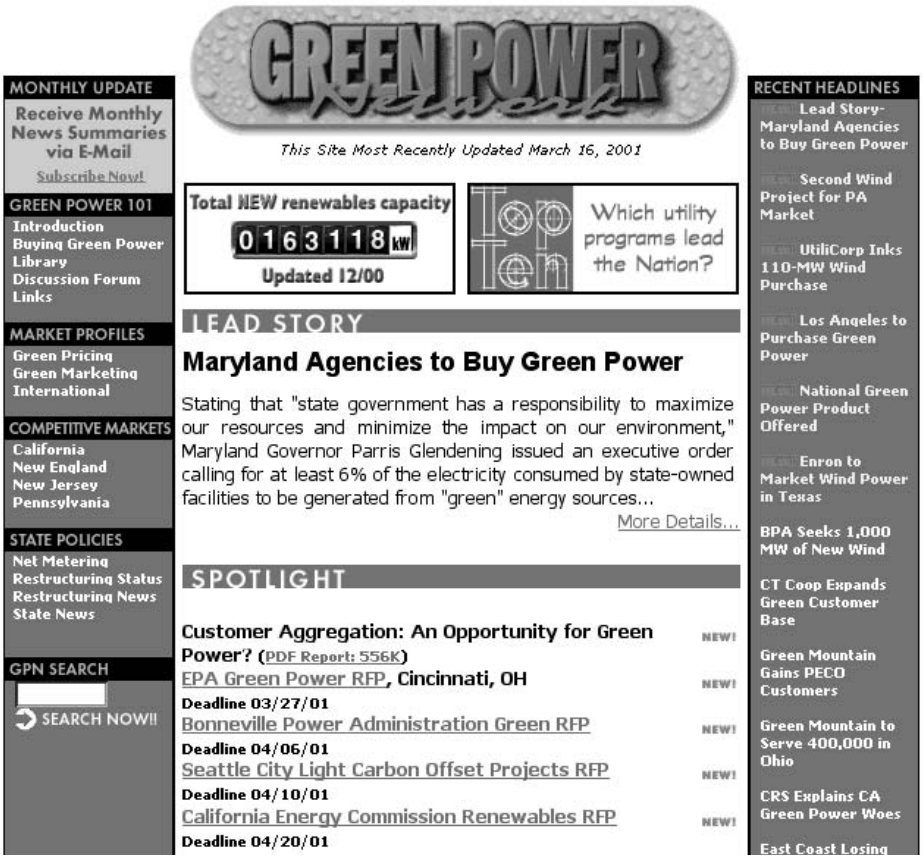
Energy Analysis

As a federally funded R&D center, NREL's Energy Analysis Office (EAO) conducts technology and application analyzes, and market and benefits analyzes for OPT and many of its individual programs. This center receives approximately two percent of total OPT funding. In addition to NREL and DOE, the customers for these analyzes 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 technical support for developing green power markets nationwide. We maintain a Green Power Network on the Internet and convene an annual Green Power Conference for the benefit of utilities, states, and green power providers.

We also analyze and 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 analyzes.

During the next five years, NREL will continue its analysis work, placing increasing attention on emerging areas such as deregulation and distributed energy resources. NREL efforts to enhance its analysis capability will add value to the Office of Power Technologies (see page 60 for energy analysis activities supporting other DOE offices).

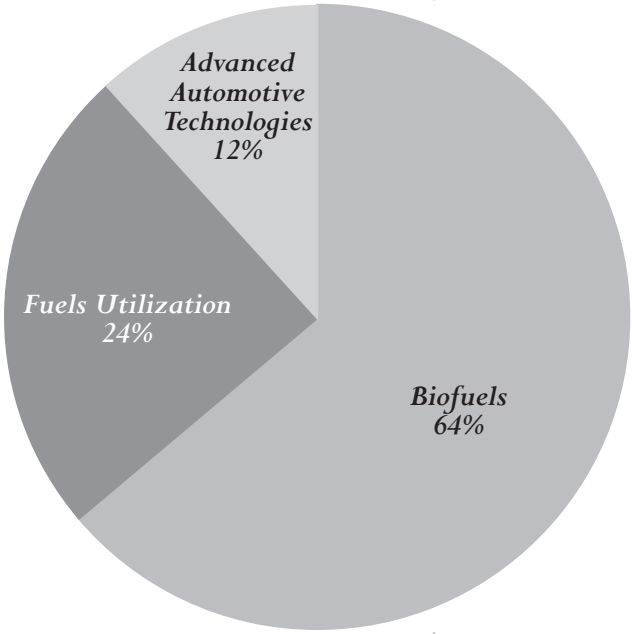


As a primary area of focus, EAO provides analyzes and technical support for developing green power markets. The Green Power Network web site benefits utilities, state, and green power providers.

THE MISSION OF EERE'S OFFICE OF TRANSPORTATION TECHNOLOGIES (OTT) is to work with the 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, as shown in Figure 11.

NREL's FY 2000 Funding from the Office of Transportation Technologies

Figure 11. Most of NREL's FY 2000 funding from the Office of Transportation Technologies supported R&D in both fuels and vehicles.



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).

The ethanol project at NREL focuses on three major DOE national program goals:

- Support the economic enhancement of corn ethanol operations where possible
- Produce ethanol commercially, using agricultural residues, by the end of 2005
- Produce ethanol from biomass commercially, using technology that eliminates the need for the ethanol tax incentive. Specifically, the target of $35/ton feedstock is $0.70/gal of ethanol by 2015.

Accomplishments in Biofuels

Established partnerships with major industrial enzyme producers for the purpose of reducing the cost of cellulase enzyme, by a factor of 10, in three to four years.

Produced the first large sample of high octane fuel from lignin. Performance tests were very encouraging.

Completed a CRADA with Arkenol to assist in their development of process guarantees for their biomass ethanol process.

Completed preliminary near IR spectroscopy-based rapid analysis method for raw corn stover feedstocks. The method reduces analysis time from days to minutes and is only about one percent of the cost of conventional analysis.

Demonstrated arabinose fermentation with whole cells in fermentation tests using highly concentrated cells. This is the first time that arabinose conversion to ethanol by a recombinant saccharomyces has been demonstrated. This work is important to the conversion of corn fiber to ethanol and was done as a CRADA with the National Corn Growers Association and Corn Refiners Association.

NREL supports the rapid commercialization of bioethanol from low-value feedstocks by collaborating with industrial partners having the best business plans, access to capital, and most favorable feedstock supplies. To reduce the cost of bioethanol production to be competitive with petroleum derived fuels, NREL will concentrate on the following tasks:

- Reduction in the cost of pretreating the feedstock, prior to enzymatic conversion
- Development of a yeast platform of improved ethanol-producing microorganisms utilizing the complete range of biomass sugars and enabling production of chemicals as well
- Conversion of residual lignin to liquid fuels.

NREL researchers grow *T. reesei*, which produces cellulase enzymes used for the biomass-to-ethanol process.

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. DOE realizes that one key to making ethanol from cellulosic feedstocks cost competitive is to reduce the cost of cellulase enzymes used to produce fermentation sugar from cellulose. To that end DOE, in partnership with NREL, has awarded multimillion-dollar subcontracts to the two largest enzyme producers in the United States. NREL will follow up their efforts with an in-house effort to insure that the complete technology for agricultural residue conversion utilizing enzymes is available for the lowest cost enzymes from these companies.

The Cost of Ethanol is Dropping

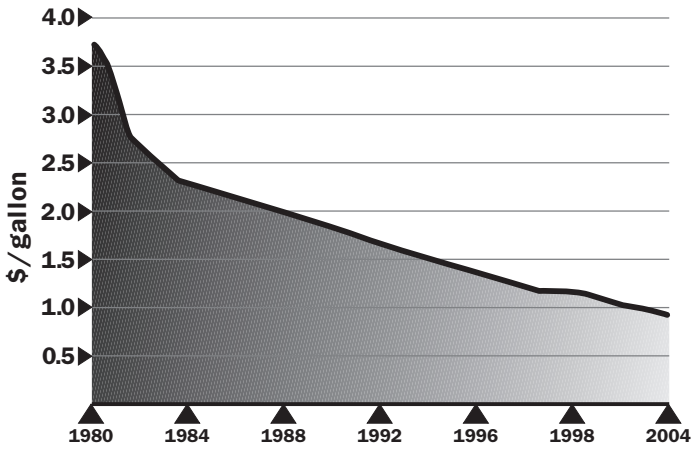


Figure 12. In 1980 it cost $3.60 to produce a gallon of ethanol; today it costs $1.20. With favorable feedstock supplies and with continued advances in metabolic engineering of cellulase enzymes and in reactor technology, the cost of ethanol production is expected to drop below $0.70 per gallon

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:

- Develop updated performance data for the enzymatic conversion of corn stover to ethanol
- Implement a corn stover-to-ethanol conversion demonstration (probably 50 T/day) with an industrial partner
- Reduce the cost of cellulase enzyme by a factor of 10 through industrial subcontracts and in-house efforts.

Biofuels are made by converting domestically grown plant materials, or biomass, into liquid fuels suitable for transportation. This not only alleviates the dependency and associated job loss of oil imports, but supports U.S. agriculture and new biofuels industries. It also provides major environmental benefits. For example, as biomass grows, it captures carbon dioxide — unlike oil and other fossil fuels for which this process happened millions of years ago — balancing the carbon dioxide released when biofuels are burned. This helps reduce greenhouse gas buildup. Use of ethanol, made by fermenting sugar made from cornstarch, is widely used in this country as an oxygenating fuel additive and to boost octane, reducing 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.

In partnership with U.S. companies, NREL's process development unit evaluates biotechnology processes to produce ethanol and other fuels and chemicals. It is the only facility of its kind in the United States.

This gas chromatograph measures hydrocarbon emissions from alternative fuel vehicles.

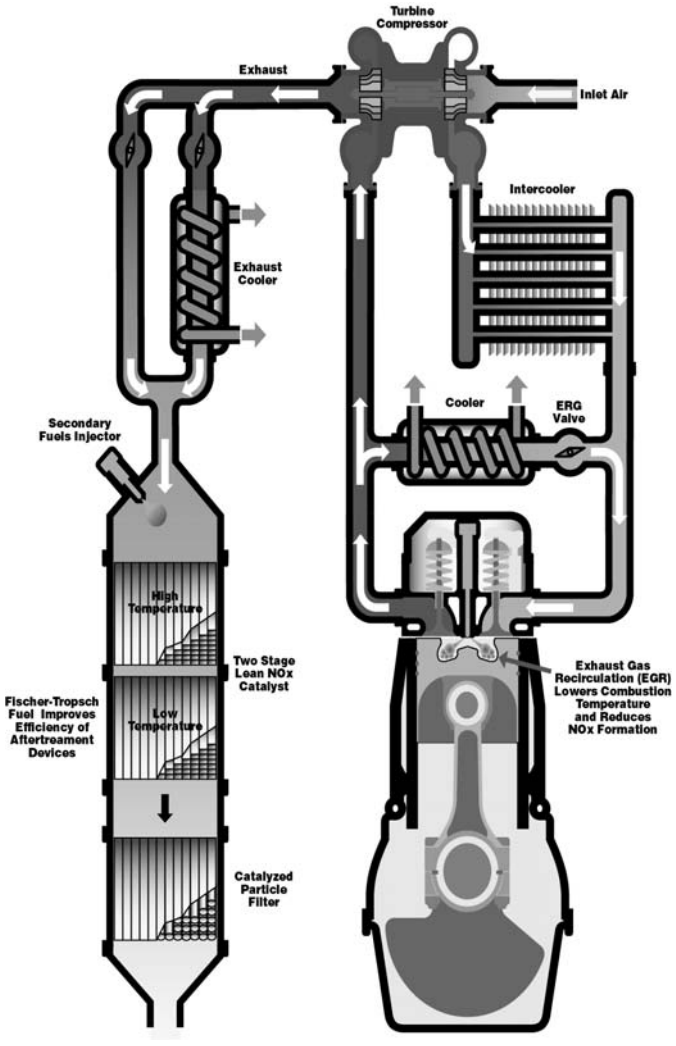
Fuels Utilization

NREL's Fuels Utilization (FU) Program receives 24 percent of OTT program funding at NREL. The goals of the program are to assist DOE in implementing parts of the Alternative Motor Fuels Act (AMFA) and the Energy Policy Act and to conduct projects to develop advanced transportation fuels and vehicle systems. The Lab provides DOE with technical leadership and expertise in technologies involving motor fuels, engines, emission control, and vehicle systems; studies developing a sound understanding of the environmental effects of transportation emissions; and moving these technologies into the marketplace. 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
- 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 pretreatment, and emission control devices.



NREL and several industry partners developed a new internal combustion engine that efficiently and cleanly burns synthetic diesel fuel. This combination of engine and diesel fuel, meets the stringent tier II standards of the EPA. This technology has been nominated for an R&D 100 award.

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).

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 motor 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 timeframe, while reducing dependence on imported petroleum.

Over the next five years, NREL will:

- Support DOE and industry in developing advanced petroleum-based fuels and lubricants for the next generation of compression ignition engines that will enable these engines to meet DOE's goals for operation at high efficiency and for meeting 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 second, more comprehensive collaborative study to understand the causes of high weekend ozone concentrations in urban areas.

NREL works in partnership with industry to help develop advanced technology vehicles such as this refuse hauler powered by a John Deere natural gas-fueled engine. The refuse hauler is part of an onroad prototype development project designed to place preproduction, alternative fuel engines into the field to move viable technology toward commercialization. As a result of this project, the John Deere engine has obtained a low emissions standards certification and is now commercially available.

Accomplishments in Fuels Utilization

Participated in a government-industry working group to test ultra-low sulfur diesel fuel and catalyzed particle filters in eight vehicle fleets operating in southern California. NREL led the preparation of the first round of emissions test plan, managed the vehicle testing, and assisted in the data analysis.

Completed on-road prototype project testing and development of a new model of advanced natural gas heavy-duty engines for trucks and buses: the Detroit Diesel Corporation (DDC) Series 60G engine. Testing on other prototype engines is underway.

Established the country's most comprehensive test program on advanced petroleum-based fuels and lubricants with broad participation including DOE, EPA, and companies from energy, automobile, truck engine, fuel additive, and emission control industries.

Advanced Automotive Technologies

NREL supports DOE's advanced automotive technologies goals by working to assist the automotive industry with developing advanced hybrid electric vehicle (HEV) technologies based on a vehicle-systems perspective. This program receives 12 percent of OTT funding at NREL.

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 DOE to "encourage and support accelerated research into, and development of electric and hybrid vehicle technologies."

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.

NREL works in partnership with industry to help develop advanced technology vehicles such as this Honda Insight. The 2000 model is a gasoline-electric hybrid and is the first of its kind to be sold in the United States. The heart of the hybrid system is Honda's innovative Integrated Motor Assist (IMA), which couples an all-new 1.0 liter, 3-cylinder engine with an ultra-thin electric motor for outstanding performance and efficiency. The Center for Transportation Technologies is testing the Insight to validate and improve its advanced vehicle simulator (ADVISOR) model, determine battery pack performance under various operating conditions, and to test effect of air conditioning on fuel economy and emissions.

Since the inception of the Hybrid Electric Vehicle Propulsion Systems Program in 1992, NREL has provided technical support and subcontract administration for DOE's program. In FY 2001, NREL will focus on closing out the subcontracts with the "Big 3" and will continue to support HEV systems development through partnerships with industry concentrating on vehicle auxiliary load reduction, battery thermal management, and vehicle systems analysis activities. This work is in alignment with the goals and critical milestones for the larger Partnership for a New Generation of Vehicles (PNGV) Program. NREL is committed, focused, and engaged with original equipment manufacturers (OEMs) and their suppliers to provide innovation in solving some of the technical barriers of the PNGV Program.

The main goal is to research, develop, and validate technologies that will enable domestic market introduction of advanced vehicles, which will have several times the fuel economy of current conventional vehicles, low emissions, fuel flexibility, and other attributes that remain competitive or add more value to conventional products.

The program objectives include the development and validation of the following:

- By 2001, identify and define any technology shortfall barriers that will preclude the application of evolving 80 mpg automotive technologies to sport utility vehicles

- By 2004, automotive technologies that will enable the achievement of 80 mpg in a full size passenger sedan
- By 2011, automotive technologies for lightweight passenger vehicles and refueling technologies that will enable achievement of 100 mpg and zero emissions in full size passenger sedans operating on fuels that can be produced from abundantly available domestic feed stocks.

During the next five years, NREL expects to:

- Continue to work hand-in-hand with industry to develop technologies and systems for hybrid electric vehicles. Focus will include reducing vehicle auxiliary loads, analyzing and modeling vehicle systems, and evaluating and improving battery thermal management systems.
- 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 and test an optimized systems design for a vehicle climate control system that reduces energy use by 50 percent
- Develop a thermal comfort manikin that simulates complex heat and mass transfer from vehicle occupants to predict occupant physiological and psychological responses to environmental conditions.
- Develop functional specifications for the next-generation medium and heavy-duty natural gas vehicles through a government-industry working group
- Develop two prototype, next-generation, medium- and heavy-duty natural gas vehicles that are fully comparable to diesel-powered vehicles.

Accomplishments in Advanced Automotive Technologies

Benchmarked the performance of various commercial hybrid vehicles to help guide research.

Directed a subcontract with the University of Toledo to develop a working prototype battery management system that could be packaged to achieve 50 percent less volume and mass, with better features and functions, than existing HEV battery management systems. This modular battery management system can help carmakers, battery manufacturers, and battery pack integrators improve performance of HEV battery packs and achieve optimum energy efficiency in hybrid vehicles.

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.

Conducted an analysis of the viability of "grid-connected" or wall-charge hybrid electric vehicles using ADVISOR as part of an industry-government consortium. From the analysis, we concluded that this hybrid electric vehicle (HEV) concept has many benefits.

Tested, in close cooperation with industry, "Cool Car" vehicle climate control technology, setting the stage for great efficiency gains from reduced need for air conditioning.

Developed an overall design for a thermal manikin, and experimentally demonstrated various skin heating and sweating concepts and a competitive solicitation for manikin construction was issued. The thermal comfort manikin is a breakthrough technology that simulates complex heat and mass transfer from vehicle occupants to predict occupant physiological and psychological responses to environmental conditions created by new cabin thermal comfort technologies and control systems.

Released ADVISOR (versions 2.2.1 and 3.0) advanced vehicle simulator to the public through the NREL Web site and held the first international users conference. Over 2500 people from around the world have now downloaded the ADVISOR software. This allows more people to have free access to state-of-the-art hybrid vehicle data and an easy-to-use model to execute vehicle simulations.

Office of Building Technology, State and Community Programs

Accomplishments in Building Technologies

Completed work on nearly 3000 energy-efficient houses as part of the Building America project, exceeding the FY 2000 goal of 2000 houses.

Determined that Building America houses with new, smaller air-conditioning systems performed 30 percent to 75 percent better than conventional homes; smaller systems could be installed because the houses' other features reduced the cooling demand.

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.

The Office of Management and Budget adopted NREL's method of conducting consumer analyzes of the impacts on consumers of new efficiency standards for certain large appliances, such as clothes washers.

Received numerous awards including American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Technology Awards for outstanding achievement in the design and operation of energy-efficient buildings for the past three years (1998, 1999, 2000); Energy User News Award for the Zion Visitor Center; Electrochemical Society award to an NREL researcher; Lifetime Achievement Award from the Passive and Low-Energy Architecture group to an NREL engineer.

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.

NREL supports BTS by conducting research in heat transfer, thermodynamics, 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. The Laboratory's research teams also help to develop advanced energy technologies that can be integrated into "whole-building" design approaches to reduce both energy costs and the greenhouse gases associated with converting conventional fossil fuels into heat and electricity. Specifically, NREL's researchers focus on the following areas:

Residential and Commercial Buildings

NREL is the field manager for DOE's Building America Program and works with the U.S. home-building industry to develop quality homes that consume 30 to 70 percent less energy than conventional homes. This, in turn, contributes to the DOE BTS goal of a 50 percent 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 PV solar water heating, and passive color design.

Advanced 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 and BESTest. 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 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, DOE BTS describes the following major objectives:

- Establishing stronger and more effective partnerships with industry and states
- Working with partners to develop government-industry technology roadmaps
- 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.

During the next five years, NREL will:

- Explore options for integrating emerging technologies like fuel cells into production buildings
- 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 and communities, incorporating energy-saving innovations
- 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 switchable window technology.

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 components, and systems, by both NREL and industrial researchers.

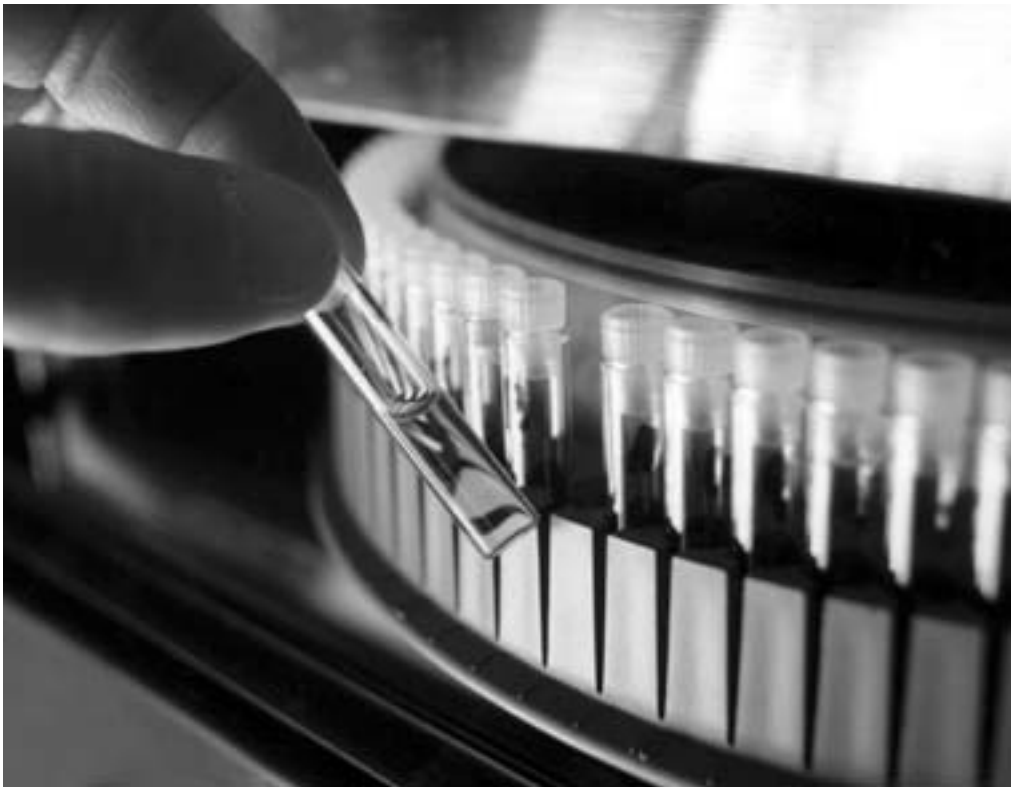
The National Park Service and NREL worked together to create this energy-efficient complex, the 7,600-square-foot Zion National Park Visitor Center. The building includes a 1,100-square-foot comfort station featuring daylighting, Trombe walls for passive solar heating, downdraft cooltowers for natural ventilation cooling, energy efficient lighting, and advanced building controls. These features are expected to result in energy cost savings of about $16,000 per year.

Office of Industrial Technologies

THE OFFICE OF INDUSTRIAL TECHNOLOGIES (OIT) creates partnerships among industry, trade groups, government agencies, and other organizations to research, develop and deliver advanced energy efficiency, renewable energy and pollution prevention technologies for industrial customers.

NREL and other DOE laboratories and facilities comprise the OIT Laboratory Coordinating Council (LCC). The nation's network of DOE laboratories and facilities holds an extensive store of research and development expertise and unique facilities and equipment developed for their various missions. NREL works with OIT to help unlock this treasure of knowledge and experience as a resource for industry.

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.



From paper mill sludge (photo far right) 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.

NREL provides technical assistance to the agriculture, forest products, chemicals, and other industries, as well as OIT's Inventions and Innovation and NICE^3 programs.

Examples of NREL's projects include:

- NREL and Eastman Chemicals have partnered to employ a NREL proprietary process for fractionating biomass into cellulose for the production of ethers and esters that are used to manufacture rayon, acetate fibers, and thermoplastics.
- Cargill Dow Polymers, the Colorado School of Mines and NREL have partnered to find new ways to modify polylactic acid to allow new applications for this biobased commodity plastic.
- The LCC has prepared a guide *Doing Business with the Laboratories of the Laboratory Coordinating Council*. This document can be found on the Internet at *www.oit.doe.gov/LCC/doing_business.shtml*.

- The Central Regional Resource Center for Innovation (CRRCI) is sited at NREL. The CRRCI coordinates financial assistance, (Inventions and Innovation and NICE^3 Programs), state Industries of the Future technical assistance and OIT Program information for a 12 state region.
- Mobile, real-time analysis of thermochemical conversion processes, such as black liquor gasification to characterize tar formation and hence provide data for process engineering of gasification unit operations.

During the next five years, NREL expects to:

- Continue its involvement in the Laboratory Coordinating Council to facilitate the interaction among NREL, other laboratories, OIT and industry
- Continue to provide communications support for OIT's programs to produce relevant documents, Web page support, and other needed items
- Continue research and development partnerships with industry in areas such as:
  —portable, rapid analysis tools for measuring the chemical and mechanical properties of biomass
  —processes for production of new plastics, e.g., polylactic acid, or polyalkanoates, derived from renewable sources
  —processes for production of value-added chemicals from complex mixtures of sugars
  —production of chemicals using "Green" processing technology
- Continue to support state Industries of the Future efforts and to provide technical assistance to the Inventions and Innovations and NICE^3 programs.

Accomplishments for OIT

1999 Green Chemistry (EPA/White House) Award to NREL, PNNL, New York State Energy Resources Authority, their industrial partners and DOE for process for making valuable chemicals from levulinic acid made from biomass materials.

2000 R&D 100 Award to NREL for the Real-Time Biomass Analysis technology for wood characterization with near infrared spectroscopy. While it was developed for the wood products industry, this technology has wide applicability to biomass materials in general. In 1999, one of the first Industries of the Future R&D awards was given to an NREL staff member for his work in forest products.

The CRADA between Eastman Chemical and NREL proceeded past a phase I demonstration of concept to fractionate biomass into cellulose for rayon, acetate fibers, and thermoplastics, and is proceeding into pre-commercialization research with a pulp manufacturer selected by Eastman Chemicals.

Major contributions to OIT/industry strategic planning and information dissemination including roadmapping efforts, conference and exposition organization, Web site redesigns, and a corporate video.

Federal Energy Management Program

NREL WORKS WITH DOE FEDERAL ENERGY MANAGEMENT PROGRAM (FEMP) staff and its private sector, and other national laboratory partners, to provide assistance to government agencies in support of the FEMP mission. The FEMP mission is to reduce the cost of government through energy and water efficiency, encouraging the use of renewable energy, and overall utility management within all federal facilities. This work is facilitated by partnerships with the private sector primarily through energy service companies, utilities, and other industry associates.

Since the federal government owns or leases more than 500 thousand 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. It is estimated that there are some $5-6 billion in cost effective energy projects in the federal sector that would result in an annual savings of some $1 billion. As this cost savings opportunity is achieved in partnership with the private sector, there is at once the creation of a $5-6 billion business opportunity. This is a classic win-win situation for government and the private sector.

DOE FEMP's three major areas of work are technical assistance; project financing facilitation; and, planning, reporting, and evaluation. One way NREL assists DOE and its government agency project partners is by providing expert technical assistance and training in identifying viable energy efficiency, water conservation and renewable energy projects for agency implementation through the private sector. NREL provided such support to 167 projects in FY 2000.

NREL's Federal Energy Management Program provided the Chickasaw National Recreation Area with a feasibility study, specifications, design review, and an inspection of this 480 square foot solar comfort station. Savings are estimated at 18,200 kWh/year.

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 DOE Regional Offices, the Golden Field Office (GO), and other laboratories to establish streamlined contracting vehicles for federal agency use in facilitating project financing in the private sector. Regional Energy Savings Performance Contracts, called Super ESPCs, and Utility Energy Services Contracts (UESCs) are these streamlined contracting vehicles that federal agencies can use to obtain private financing for projects.

NREL has the technical lead in four of the six Regional Super ESPCs and assisted with ESPC projects in FY 2000 totaling $79 million in private sector investment. NREL also is the lead in project assistance support to UESC projects and assists the Utility Program in a number of additional ways including facilitating green power procurements, and addressing the implications of utility restructuring. NREL assisted with utility projects in FY2000 totaling investments of $38 million.

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 UESC. 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. NREL reached over 3000 federal agency customers in FY 2000 with this support in the initial phases of project creation.

FEMP is well on its way in having put in place the capabilities and streamlined procurement mechanisms needed to support the federal agencies in being able to capture significant energy cost savings. Over the next five years, NREL expects to continue to provide and grow its demonstrated and extensive technical assistance, project financing facilitation and outreach capabilities to energy managers, procurement officers, and project leaders in the federal government.

These solar troughs provide solar heat and hot water for the Adams County Detention Center. With technical assistance from NREL, Industrial Solar Technology developed the parabolic-trough solar thermal water heating systems—providing low-cost hot water for several public facilities throughout the Southwest.

Accomplishments in FEMP

Reached more than 3000 federal customers and industry partners through twenty-one workshops, thirteen working group presentations, eight industry forums, twenty-five conference presentations, and sixteen customer/industry meetings.

Provided support to 167 energy efficiency and/or renewable energy projects. Out of those projects, 21 were awarded with a project investment of approximately $79 million in energy efficiency and renewable energy equipment resulting in more than one million Btu's saved and a cumulative cost savings of over $110 million over the life of the projects.

Conducted a customer feedback survey of federal customers assisted by NREL in which the results indicated 96 percent of the customers felt we either met (23 percent) or exceeded (73 percent) their expectations.

Completed thirty publications and started an additional nine during FY 2000.

Assisted with the development and award of a $38 million Utility Energy Services Contract between the National Institute of Health, the General Services Administration, and their electric utility, PEPCO, in the Washington, D.C. area. This project will save approximately $4 million each year in utility bill savings.

Office of Planning, Budget, and Management

NREL CONDUCTS, ANALYZES AND PROVIDES the primary information outreach mechanisms for DOE through EERE's Office of Planning, Budget, and Management.

Accomplishments and Emphases in Energy Analysis

Continued to develop of technology characterizations for renewable energy technologies.

Provided analysis and technical support for green markets.

Provided 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 the dilemma of ever-increasing energy demand for personal mobility versus increasing dependence on oil imports.

Continued to develop sound projections of the future energy contributions and ancillary benefits likely to result from energy efficiency and renewable energy programs.

Launched REASN, an Internet platform designed to enhance the execution and communication of energy analysis.

Conducted a series of seminars for the energy analysis industry on a range of topics that are presently affecting the energy arena.

Energy Analysis

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
- Projecting the future contributions and benefits of clean energy technologies
- Evaluating the impact of federal environmental air emissions regulations on the competitiveness of renewable technologies
- Supporting the formulation of sound clean-energy policies.

NREL conducts studies across a range of topics to serve these diverse analytic needs. We analyze past, current, and projected energy markets to understand the context in which clean energy technologies will operate. We look at specific market sectors to understand energy applications and their implications for our technology development activities. We conduct analyses of the impacts of alternative energy policies and programs to provide the understanding needed to guide and inform energy program and policy decision makers.

NREL has also begun the development of an enhanced clean energy analysis capability that will draw upon and apply the best analytic talents worldwide to address the various issues facing DOE's clean energy programs. This enhanced capability will include use of in-house expertise as well as unique capabilities of several renowned analytic groups in universities and private institutions. NREL will serve as the manager and integrator of this overall collaborative analysis program, enabling ready access to individual capabilities and expertise as need for specific analytic issues. As a framework and tool to facilitate this collaborative effort, NREL is developing an Internet platform to enhance the execution and communication of energy analysis using current databases, the best available analytic tools, transparent methodologies, and ready review, dissemination, and discussion of results. The overall goal is to develop and provide the nation with an energy analysis center of excellence comparable to our several national energy technology centers, such as the NWTC and the NCPV.

REASN, NREL's Renewable Energy Analytic Studies Network, is the Internet platform that was recently launched to enhance the execution and communication of energy analysis to provide the nation with an energy analysis center of excellence.

Information and Outreach Program

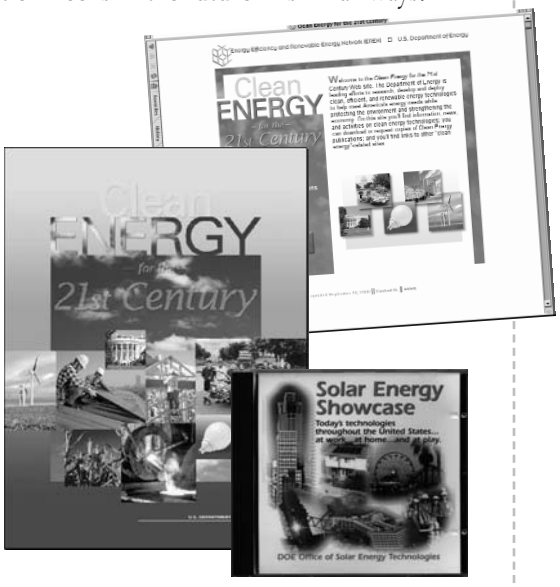
The Technical Information Program and Information Services Program were consolidated this year to create the Information and Outreach Program.

NREL manages and maintains 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 acts as the umbrella Web site for all of EERE information from all EERE sector and program sites.

From feedback and suggestions obtained in a user survey and two focus groups conducted in FY 1999, NREL embarked upon a massive restructuring project of the EREN Web site. This effort will be completed in March 2001. The newly restructured site will enhance EREN's role as a portal Web site for all EERE information, in addition to its major function as the corporate Web site for EERE. NREL will also be conducting EREN's first benchmarking study, to see how it compares to similar sites. This will offer insight for our efforts to continually improve the site and keep up with the latest in information technology.

NREL also oversees the operation of the Energy Efficiency and Renewable Energy Clearinghouse (EREC). EREC is set up to receive and respond via phone, fax, mail, and e-mail to more than 60,000 consumer inquiries about energy efficiency and renewable energy. EREC helps consumers with everything from how to identify an energy-efficient appliance to alternative energy sources for the home and school science projects. Even though it now features a Consumer Energy Information Web site on EREN, EREC still provides the customized and personal assistance not available on the Web and to those who don't have access to the Web. In the future, NREL will continue to ensure that EREC provides new and updated information to consumers, monitor customer satisfaction, and encourage NREL and EERE staff to utilize EREC, at no cost, for storing and disseminating their current outreach publications and products.

NREL works with EERE, Sectors, and Programs to prepare many different types of technical communications to enhance the awareness of EERE's technologies. Products include outreach campaigns, 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.



Brochures, Web sites, and CD ROMs are some examples of information and outreach products produced at NREL.

Information and Outreach Program

Worked on a total of 63 Web sites: 21 new sites, 14 redesigns, and performed significant work on 28 other sites.

Restructured eight of the eleven technology sections on EREN.

Disseminated through EREC 242,000 publications and products for EERE.

Created the OPBM Web site.

Produced and distributed the BTS quarterly newsletter.

Produced fact sheets, brochures, a video, Web sites, and other communications products for OIT's Expo.

Updated and posted the OPT Success Stories.

Created a media room on the OPT Web site containing DOE and OPT press releases and a link to a utilities section on PIX.

Created, printed, distributed, and posted a Spanish version of the ever popular "Tips for Energy Savers" booklet.

Developed a specialized resource on EREN to serve as a portal for state resources and funding.

Updated the "Consumer Information" section on EREN to provide more content.

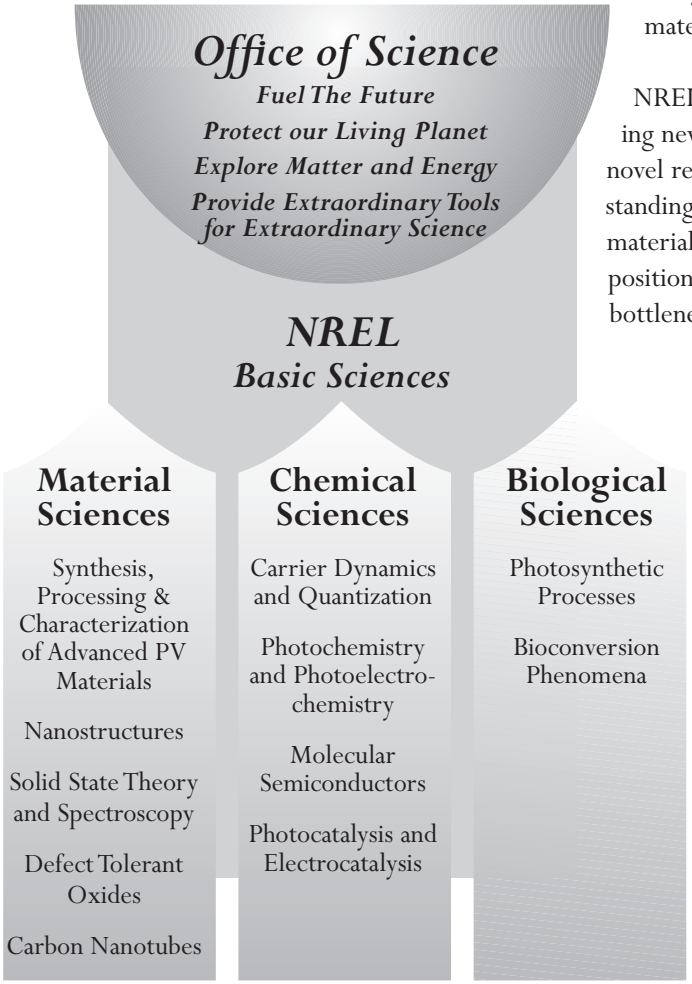
Completed an extensive redesign of OIT's Best Practices Web site, a DOE "Site of the Month" selection.

Office of Science

AS DOE'S PRIMARY SPONSOR OF BASIC RESEARCH, the Office of Science provides the scientific foundations for DOE's applied missions. In support of the DOE mission and goals, the Office of Science focuses on 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 (Figures 13 and 14). In addition, NREL integrates the results of the basic research it performs under the purview of the Office of Science with the more applied objectives of EERE.

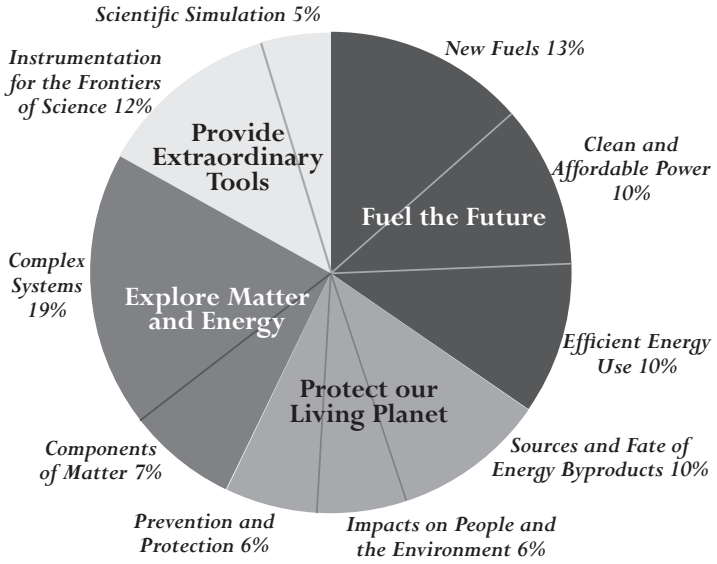
NREL supports the BES and SC missions and goals by conducting R&D that emphasizes renewable energy technologies such as photovoltaics and other means of exploiting solar energy. NREL performs its research primarily in three areas — materials sciences, chemical sciences, and energy biosciences.

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 at gaining a fundamental understanding of the phenomena and properties important to the behavior of materials. NREL's activities include novel ordered semiconductors, composition modulation, defect-tolerant oxides, solid-state theory, doping bottlenecks in semiconductors, and carbon nanotubes for CO_2 removal.



NREL's Support of the Office of Science

Figure 13. NREL performs research in the materials, chemicals, and biological sciences in support of the Office of Science themes: Fuel the Future, Protect our Living Planet, Explore Matter and Energy, Provide Extraordinary Tools for Extraordinary Science.



NREL Contributions to the Office of Science

Figure 14. This chart shows NREL contributions to ten of the twelve major themes in the Office of Science as a proportion of FY 2000 funding weighted by our contribution to each theme.

Source: Bob Vallorio, DOE Office of Science.

Novel ordered semiconductors

Some important classes of semiconductors — such as gallium arsenide and its alloys, or copper indium diselenide and its alloys — often exist in disordered states (i.e., there is no regular spacing between the atoms making up the semiconductor). Under certain growth conditions, however, these same materials can spontaneously exhibit order (i.e., the spacings and structure become regular, such as in a crystal). Such spontaneous ordering can dramatically affect important properties of the semiconductor material. It can, for example, modify a material's band gap, and hence modify the kind of light the material will absorb and how efficiently it absorbs it. It can also change the efficiency with which the absorbed light can produce charge carriers and the efficiency with which the charge carriers may be collected to produce a current.

By controlling the order of such semiconductors, NREL researchers will be able to control important semiconductor properties. This, in turn, could result in important materials and structures for making efficient PV, optoelectronic, and lasing devices.

Toward this end, NREL researchers are growing novel-ordered semiconductor alloys using the growth methods of metal-organic chemical vapor deposition and molecular beam epitaxy. They are also characterizing the electrical, optical, and structural properties of these compounds. Plus, they are developing a theoretical model to explain and predict the ordering of a variety of novel-ordered semiconductor alloys.

Composition modulation

When a thin binary layer of certain III-V semiconductor alloys — such as aluminum indium arsenide or aluminum indium phosphide — are grown on a substrate, under the right conditions the composition of the alloy modulates (i.e., changes periodically in an orderly fashion) in the plan of the layer. By properly orienting the substrate, the modulation can be produced in different configurations — in lateral strips, in centered rectangular arrays, and other regular patterns.

Composition modulation has several potentially important applications in photovoltaics, solid-state lasers, and other applications. In photovoltaics, for example, composition modulation can be used to vary the band gap of a material to the desired level, while lattice matching the material to a desired substrate — important considerations for making high-efficiency photovoltaic devices. Also, rectangular-centered modulation holds the potential for growing regular, consistent-sized quantum dots (small semiconductor boxes of nanometer size that hold from tens to hundreds of atoms) for use in solid-state lasers with uniform frequencies and low threshold currents (resulting in lasers that are efficient and that provide light with precise, desired energies).

In this project NREL researchers are cooperating with researchers from Sandia National Laboratories to grow materials that exhibit both lateral and rectangular modulation. NREL researchers are then using a variety of optical spectroscopic techniques to study the properties of these materials. This work should result in the ability to understand and control composition modulation in several important semiconductor alloys.

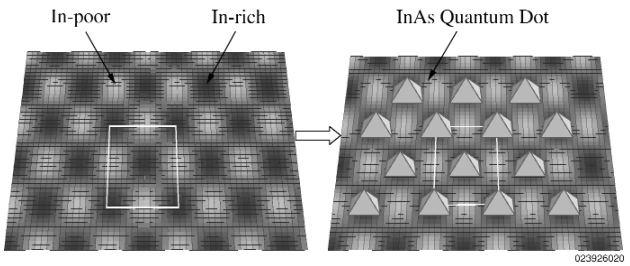


Figure 15. One concept for AlInAs composition modulation is to create a centered-rectangular, two-dimensional lattice with In-rich and In-poor areas, then to use the In-rich areas on which to grow uniform InAs quantum dots of controlled size.

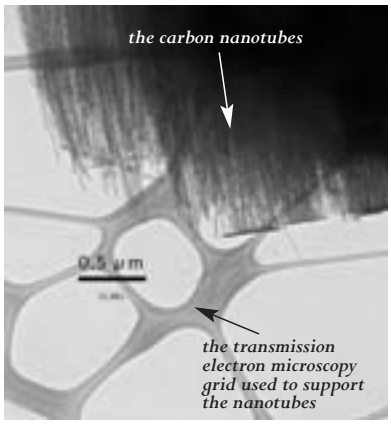


Figure 16. NREL's research on carbon nanotube membranes focuses on the transport of gases through well-defined arrays of small, aligned, graphitic pores. Such pores are produced by forming carbon nanotubes within alumina templates using chemical vapor deposition, or by manipulating and arranging single-wall carbon nanotubes made by laser vaporization.

Defect-tolerant oxides

Because of their structural and electronic tolerance for large doping or defect levels, defect-tolerant oxides are becoming increasingly important for many of the solid-state structures and devices that NREL investigates for renewable-energy systems — including photovoltaics, transparent conducting oxides for use in photovoltaics, long-lasting, rechargeable batteries, and electrochromic and photoelectrochromic layers for use in smart windows and displays.

This program is trying to understand the relationships between the structure and the electro-optical properties in this oxide materials. Initial work has focused on V_2O_5 and $LiCoO_2$, which are important cathode materials for Li batteries. Researchers will extend their investigations to include the technologically important MnO-based systems, transparent conductors, and ferroelectric and dielectric materials. They will also expand their research to include combinatorial materials growth as a method to quickly discover and optimize new materials that may be used for renewable energy applications.

Solid-state theory

The solid-state theory group uses fast computers and quantum mechanical strategies to search for new, stable electronic materials, and it investigates the theoretical foundations of photovoltaic materials, quantum nanostructures, and order-disorder phenomena. To look for new materials, the group is developing an approach called LEGO (linear expansion of geometric objects), which is based on the recognition that complex crystal structures can be viewed as a collection of simple geometric objects. For photovoltaic materials, theorists use first-principles electronic structure theory to explain and predict material properties and electronic structure of materials and to explain why some semiconductor materials exhibit long-range order. For quantum nanostructures, scientists use psuedopotential many-body theory to predict optical and transport properties of semiconductor quantum dots, including "colloidal/free-standing" dots of Si, CdSe, and InP, as well as "self-assembled" dots of InAs/GaAs.

Doping bottlenecks

Many semiconductors cannot be doped to desired levels, particularly those with wide band gaps. Recent rapid progress in semiconductor research mandates that these limitations be overcome in order to tune semiconductors for precisely required properties. In this project, researchers are investigating doping bottlenecks using first-principles, total-energy calculations. The bottlenecks are caused by dopant solubility that is too low, donor/acceptor levels that are too deep, or the formation of intrinsic defects. Researchers are proposing new strategies for overcoming these problems.

Carbon nanotubes for CO_2 removal

Because of concerns associated with global warming, improved methods are needed for removing CO_2 from the hydrogen produced by steam reformers and partial oxidation reactors. NREL scientists are researching two areas: membranes fabricated using carbon nanotubes that either block or selectively transmit CO_2; and using carbon nanotube powders that discriminate between different molecules by competitive reactions during pressure swing adsorption. This research capitalizes on tunable properties of both the membranes and powders, which bestow unique behaviors and advantages. This project shares synergies with an NREL project funded by EERE, as well as a cooperative research and development agreement with Honda R&D Americas that focuses on hydrogen storage in single-wall carbon nanotubes.

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. NREL's investigations in chemical sciences involve the research areas of dye-sensitized photochemical solar cells; quantum dots; interfacial photochemical processes; photoconversion processes in molecular semiconductors; and basic research in C_1 electrocatalysis.

Fundamental studies of dye-sensitized photochemical solar cells

The photochemical solar cell is a potentially low-cost, efficient solar cell based on dye-sensitized nanocrystalline films of titanium dioxide (TiO_2). This device contains a photoelectrode made of a nanocrystalline film of TiO_2 particles. Dye molecules 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 electrolyte and become part of a series of reactions that restore the oxidized dye molecules to their original state to complete the energy conversion cycle. Research in this project focuses on several aspects of charge carrier dynamics, charge generation, the influence of light intensity, photostability, and the use of quantum dots to sensitize TiO_2.

Quantum dots

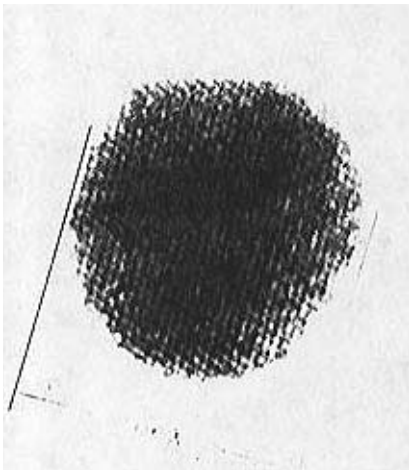
Quantum dots are semiconductor particles that typically have a radius that ranges from 2 to 25 nanometers. They exhibit extremely interesting optical, electronic, and photoelectrochemical properties that are a function of their size. Quantum dot arrays — which are formed by assembling quantum dots into close-packed ordered or disordered structures — also have unique and important properties that may be useful as photoelectrodes in photon conversion systems. In this project researchers are using a variety of spectroscopic and other techniques to study the fundamental properties of III-V quantum dots and quantum dot arrays, developing the basic science underpinning the use of quantum dots and arrays in semiconductors, and exploring unique properties of quantum dots that may impact their application.

Semiconductor quantum dots

Semiconductor quantum dots represent a new class of materials between molecules and bulk solids. They are large enough to maintain the bulk crystal structure and small enough to produce quantization effects. These characteristics make them extremely promising for use in highly efficient photoconversion systems. In a project to synthesize quantum dots, NREL researchers are making quantum dots of a variety of III-V semiconductor materials, investigating the influence of organic stabilizers and various matrices, and exploring the mechanisms of energy transfer and carrier dynamics.

Interfacial photochemical processes

Chemically modifying the nanocrystalline TiO_2 electrodes of a photochemical solar cell improves the performance of the device and increases its photovoltage. The objective of this project is to understand how this happens by resolving issues involving the mechan-



In ultra-small particles of semiconductor material, researchers are studying "quantum dots" where the material confines electrons to ultra-small regions of space. The atomic planes are visible as rows in this image, which was produced by a high-resolution transmission electron microscope (TEM).

NREL researcher holds a flask containing one of the dyes she has synthesized to absorb visible light and transfer energy.

ics and kinetics of charge transport and recombination across the nanocrystalline/electrolyte interface, the separability of the ion and electron diffusion process, the electrical potential distribution in the cell, the location of the charge separation, and the mechanism of photopotential generation. Researchers are addressing these issues through experimental studies using electrical impedance and optical modulation spectroscopy, and through theoretical approaches to provide an understanding of the effect of experimental parameters on electron-transport rate measurements.

Photoconversion processes in molecular semiconductors

In this task, researchers seek to understand fundamental aspects of photoconversion processes in organic-based systems by studying energy transfer processes and the generation, separation, and recombination of charge carriers in molecular semiconductors and dye-sensitized solar cells. A particular focus involves studying these processes in self-organizing films of liquid crystalline molecular semiconductors. These compounds were synthesized in the belief that highly ordered films may reveal the intrinsic properties of molecular semiconductors more clearly than the usual amorphous or polycrystalline films deposited by thermal evaporation.

Recently, researchers have invented a procedure for correctly doping molecular semiconductors for the first time, increasing the conductivity by a factor of more than 100 in initial experiments. Since the low conductivity of molecular semiconductors is often a major factor limiting their photoconversion efficiency, NREL scientists are optimistic that this doping technique will eliminate this problem and thereby open a new area of research in the field of molecular semiconductors.

C_1 electrocatalysis

It is possible to remove CO_2 directly from the atmosphere, use catalytic electrochemical reduction to convert the CO_2 to fuels (such as methanol), and then to catalytically oxidize the fuels back to CO_2 with the production of electrical energy (using fuel cells). Doing this with electricity derived from renewable energy sources (such as solar cells or wind turbines) offers an attractive renewable route to fuels that would not produce a net increase in atmospheric CO_2 concentrations. Critical to this is the development of electrocatalysts that would enable the processes to proceed efficiently.

With this project, NREL researchers are collaborating with researchers from several universities to develop highly efficient methods for separating and recovering CO_2 directly from the atmosphere; discover and optimize new C_1 electrocatalysts; and develop a fundamental understanding of the kinetics and thermodynamics of key catalytic steps involved in the interconversion of C_1 products.

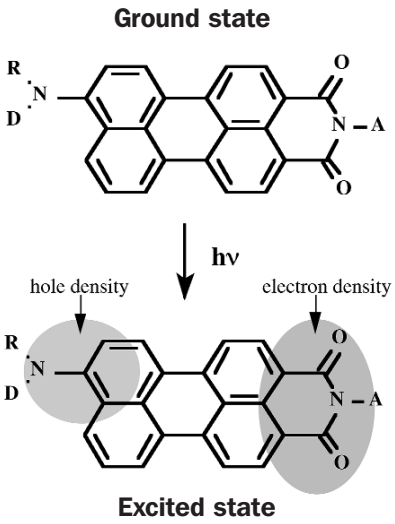


Figure 17. The photo excitation of a charge-transfer dye polarizes its electron density. One of the questions researchers are trying to answer is whether this polarization affects the efficiency of electron and hole transfer

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 to address environmental problems. Two Office of Science projects are contributing to the base of fundamental scientific knowledge related to photobiological conversion of sunlight into fuels and chemicals (photosynthesis).

Water-splitting apparatus of photosystem II

Photosystem II is one of two light reactions of algal and green plant photosynthesis. NREL researchers have succeeded in measuring the picosecond time-domain, charge-separation reactions in this photosystem that provide energy to drive plant metabolism. They have also imaged that part of the membrane/protein structure that performs these basic processes, and examined fundamental aspects of the system that releases molecular O_2 from water.

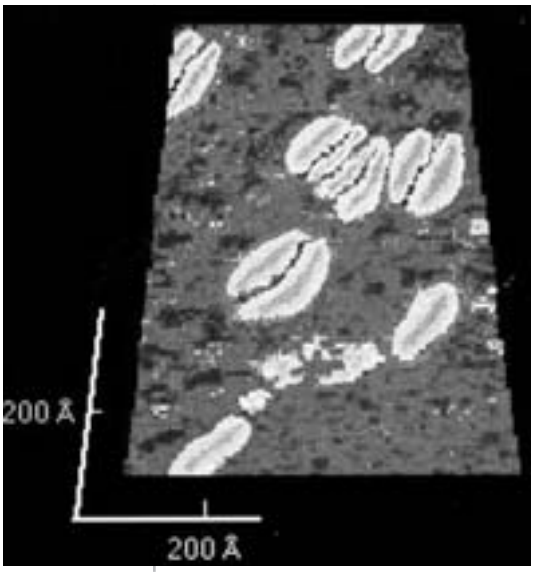


Figure 18. This scanning tunneling micrograph shows the luminal surface of granal membrane fragments isolated from spinach, which are enriched in photosystem II water-splitting activity.

Regulation of hydrogen metabolism

This research involves the regulation of H_2 and CO_2 metabolism in algae. Scientists from NREL and UC Berkeley have produced significant amounts of H_2 from water using common algae in research supported by the EERE Hydrogen Program. Their method is based on growing the algae under normal photosynthetic conditions (O_2 is evolved) and then withholding sulfur (stops net O_2 production and promotes H_2 evolution). The Office of Science is supporting work aimed at understanding this process at the molecular level by examining the mechanism of hydrogenase (the H_2-releasing enzyme) induction and partitioning of electrons from water to the enzyme to maximize hydrogen production.

A set of bio-reactors used for photobiological hydrogen production by green algae. The system consists of two stages. In the first stage, the algae are grown photosynthetically. In the second stage, critical nutrients are removed. In the light, the cells gradually inactivate their photosynthetic oxygen evolution and remove all residual oxygen. Once this happens, the algae will produce hydrogen for several days.

Integration of Basic and Applied Research

NREL IS MAKING A CONCERTED EFFORT to integrate the basic energy research funded by the Office of Science with applied research supported by EERE. Recognizing that basic research activities provide the scientific underpinning for advancing present and future renewable energy technologies, NREL has several projects under way that have been co-funded and co-planned to meet this objective.

Dye-sensitized photoelectrochemical solar cell

This promising new cell is built of simple and inexpensive ingredients: titanium dioxide nanocrystalline films and ruthenium-based dyes absorbed on nanoparticles. Fundamental research funded by the Office of Science is directed at understanding the basic photo-generated carrier dynamics of heterogeneous electron transfer and transport in these cells and other fundamental mechanisms. EERE funds are used for applied research to optimize the device parameters that determine performance and efficiency of these cells.

High-efficiency tandem solar cell

Developed in a joint effort with the PV Program, the 30 percent-efficient tandem cell was a significant evolution of NREL technology. The top cell ($GaInP_2$) captures the high-energy part of sunlight and passes the rest to the bottom cell (GaAs) for absorption. The two materials have matching lattices, which allows them to be grown in a single reactor system. The achievement was based on gaining a fundamental understanding of the optoelectronic properties of the materials and applying this understanding to the optimization of device parameters — an integration of basic and applied research that enabled scientists to control growth conditions so they could precisely tune the characteristics of the cell materials. This technology has been transferred to industry and is now routinely used to power space missions.

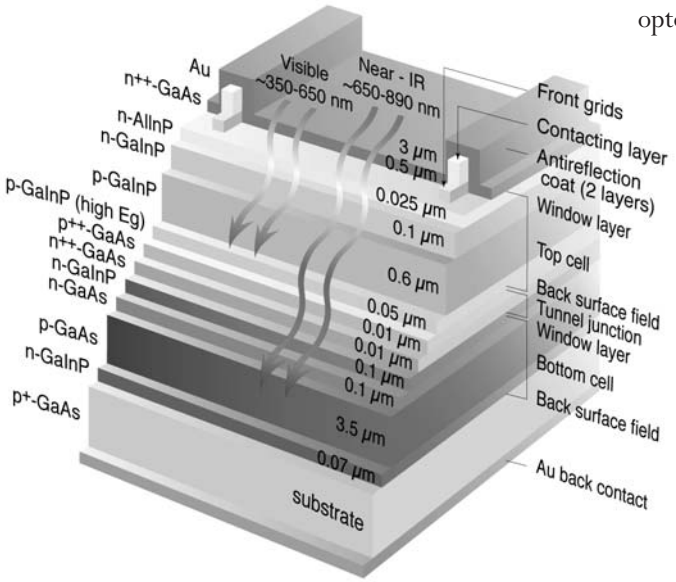


Figure 19. Device structure of 30.2 percent-efficient $GaInP_2$/GaAs two-junction PV cell. Success with this cell is leading toward three-and four-junction cells

DOE Center of Excellence for Synthesis and Processing of Advanced Materials

Because of its strengths in both applied and basic photovoltaics research, NREL coordinates this Center of Excellence. Participants include numerous labs and universities who perform collaborative research in high-efficiency photovoltaics. Recent progress in silicon-based thin films includes improved growth and characterization techniques. Regarding next-generation thin-film materials, the focused effort to develop GaInAs:N as a one electron-volt material for very high-efficiency photovoltaics is proving worthwhile. Much interest has been generated within the scientific community around the effect of nitrogen incorporation on the band gap of the host material.

Operations and Infrastructure

Human Resources

Safeguards and Security

Site and Facilities Management

Existing Conditions

Site Operations

Site and Facilities Objectives

Site and Facilities Investment

Integrated Safety Management

Information Management

Science and Technology Education Programs

Intellectual Property and Technology Transfer

Director's Discretionary Research and Development Program

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 863 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 ongoing 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 and managers; 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
- 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, which includes a sabbatical leave program
- Becoming a learning organization through diversity.

Table 1.
Education Level of Laboratory Staff

	No Degree	Associate	BS/BA	MS/MA	PhD	Total
Administrative	19	3	40	23	9	94
Clerical	94	4	21			119
Communications	1		30	15		46
Computer Science	20	6	19	9		54
Engineers	4	3	41	49	28	125
ES&H		1	5	2		8
Group Managers	2	1	7	12		22
Operatives	2					2
Program Managers			5	8	7	20
Project Leaders	1		16	20	9	45
Protective Force	5	1	1			7
Research Participants	38		4	2	10	54
Scientists		2	34	31	92	159
Senior Managers — ADM	1		3	3	2	9
Senior Managers — R&D			3	3	7	13
Skilled Craft Workers	12	5	7			24
Technicians	30	9	15	3		57
Unskilled Laborers	5					5
Total	**233**	**35**	**251**	**180**	**164**	**863**

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 ongoing 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. Currently females fill 30 percent of our top-level management positions.

In addition, the Laboratory has 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 and recruit 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.

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	2	27	53	2	2		2	33	61
Clerical			4	4	13	85	2	10		1	19	100
Communications					11	32		3			11	35
Computer Science	3	2	1		24	21		2		1	28	26
Engineers	9	1			96	17	1			1	106	19
ES&H					4	4					4	4
Group Managers			1		10	11					11	11
Operatives					2						2	
Program Managers					17	3					17	3
Project Leaders	2	2		2	23	14		1	1		26	19
Protective Force					4	1	2				6	1
Research Participants	4	3			30	14	2	1			36	18
Scientists	15	5		1	110	22	5	1			130	29
Senior Managers — ADM					6	3					6	3
Senior Managers — R&D	2	1			9	1					11	2
Skilled Craft Workers	1		4		15	3	1				21	3
Technicians	1		1		37	14	2	1	1		42	15
Unskilled Laborers			2		2		1				5	
Total	**38**	**16**	**16**	**9**	**440**	**298**	**18**	**21**	**2**	**5**	**514**	**349**

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.The Laboratory has an open campus, with easements giving access to hiking trails, paths, and other outdoor recreation areas adjacent to and on top of the mesa.

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. During FY 2000, NREL participated in the Golden Field Office's Surveillance Program to evaluate the Security Programs.

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 FY 2000, NREL developed and implemented an enhanced electronic Site Access Form to facilitate manager approval and accountability for building and information access levels.

During the next five years, we expect the level of security at NREL to remain consistent. In addition, we will be issuing new photo identification badges to all NREL staff as directed by DOE Notice 473.4.

We anticipate our next regularly scheduled Safeguards and Security Inspection to be held in 2001.

The first structure visitors and NREL staff see as they approach the permanent site is the Site Entrance Building (foreground) which houses the Laboratory's emergency control center and seven Protective Force Officers. The Visitors Center can be seen in the background.

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 635,000 gross square feet (ft²) of DOE-owned or leased space (all sizes are given as ft²). Of this total, about 40 percent is leased. Table 3, Laboratory Space Distribution, summarizes the land area and occupied space information on each site.

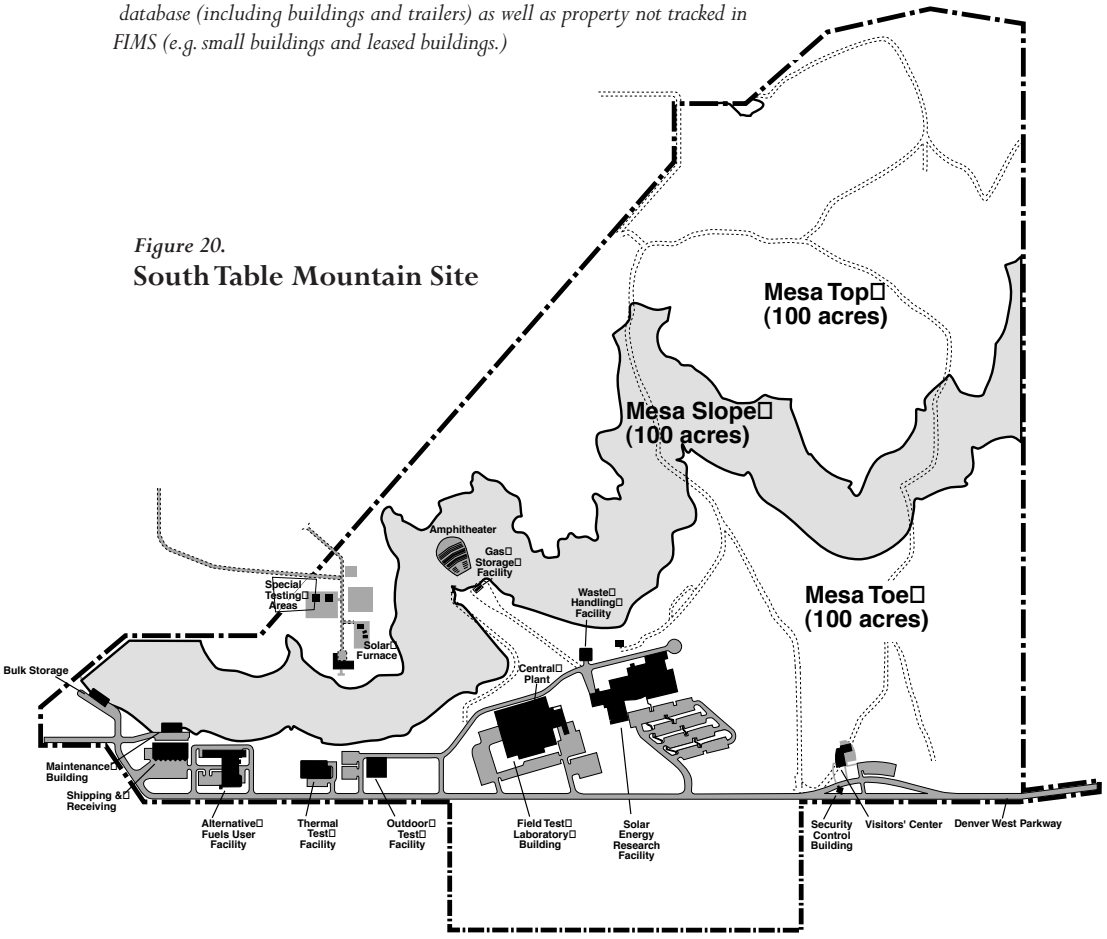
Table 3.
Laboratory Space Distribution

Location	Land Area (acres)	% of Total	Occupied Space (feet²)	% of Total	Total Staff
STM	327*	53	323,000	51	392
NWTC	280	45	52,000	8	100
Leased Off Site	11	2	260,000	41	533
Total	**618**	**100**	**635,000****	**100**	**1025**

* *Approximately 177 acres are restricted via a conservation easement.*

** *Includes space tracked in the Facilities Infrastructure Management System (FIMS) database (including buildings and trailers) as well as property not tracked in FIMS (e.g. small buildings and leased buildings.)*

Figure 20.
South Table Mountain Site



South Table Mountain Site

The STM site (Figure 20), with 136 acres of developable land, is located on the toe, side, and top of a mesa. Because of the topography of this site, 177 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 community 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 STM 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.

This aerial photo shows NREL's primary research facilities at the South Table Mountain site. In cooperation with the state and county, the mountain's mesa sides and top were put into open space easement in exchange for 25 acres of additional buildable land adjacent to the primary research site.

Solar Energy Research Facility
Completed in 1994, this 116,000-ft^2 laboratory is an energy-efficient showcase that has won numerous architectural design awards. Using 36 percent 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.

The Solar Energy Research Facility is designed to be one of the most energy-efficient buildings in the federal government and serves as a model for efficient office daylighting.

Field Test Laboratory Building

Completed in 1984, this 118,000-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 29,000 ft² 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.

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 192,000 ft² in four different buildings.

The Field Test Laboratory Building, NREL's multi-purpose research facility, houses work in many different program areas and is frequently modified to accommodate research changes.

NREL's administrative activities, and some laboratory research, are housed in leased office buildings in the Denver West Office Park about 1 1/2 miles from the South Table Mountain site, which is seen in the background of this aerial photo.

National Wind Technology Center

This 280-acre site (Figure 21) 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.

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. Portions of Rocky Flats land could be used for additional systems and field testing in several program areas.

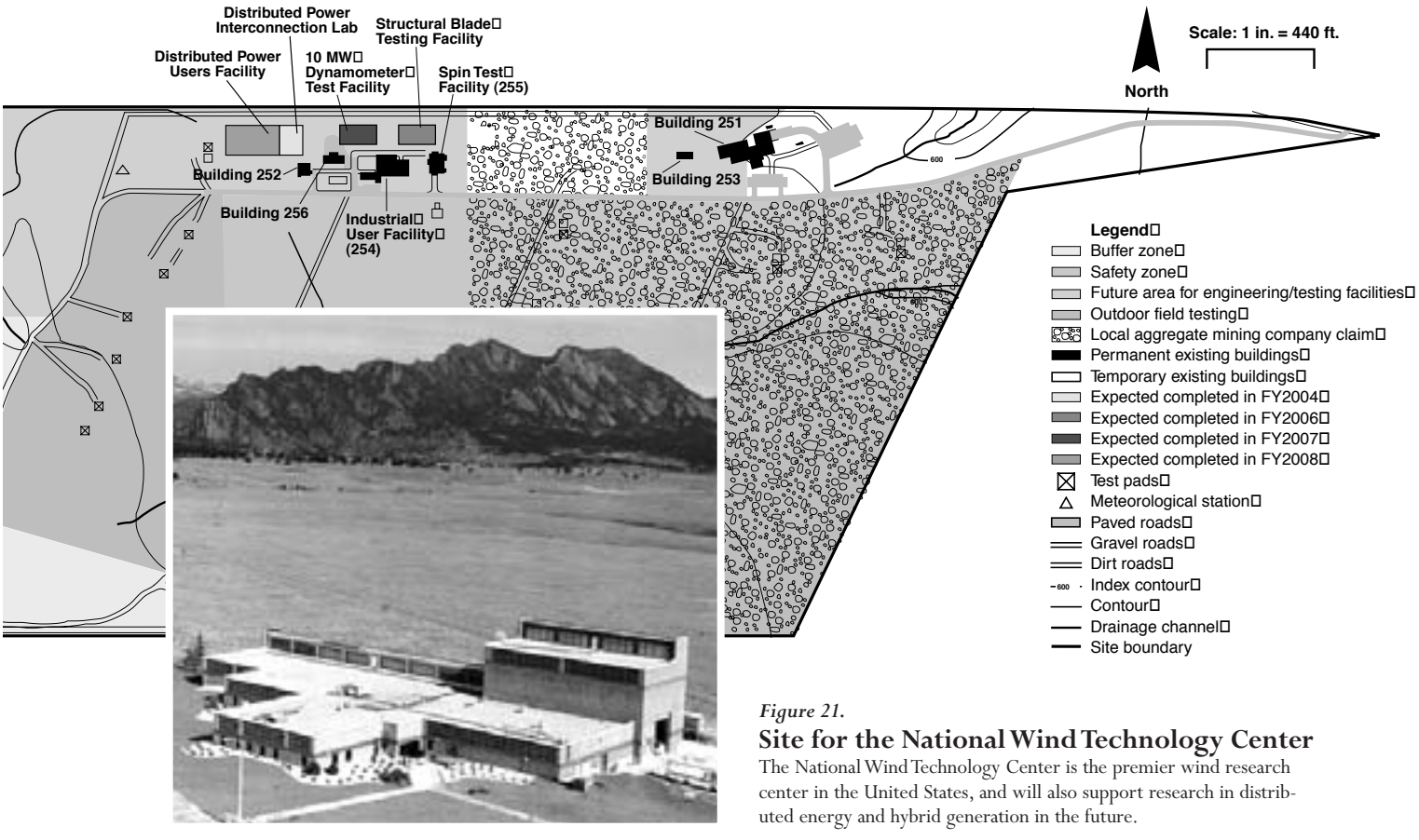


Figure 21.
Site for the National Wind Technology Center
The National Wind Technology Center is the premier wind research center in the United States, and will also support research in distributed energy and hybrid generation in the future.

Maintenance and Development of Infrastructure

NREL opened in 1977. As shown in Figure 22, 75 percent 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 Figure 23, 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 percent 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 percent (based on acquisition cost) of NREL's capital equipment, both general purpose and program capital, continues in use beyond its expected useful life.

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). 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.

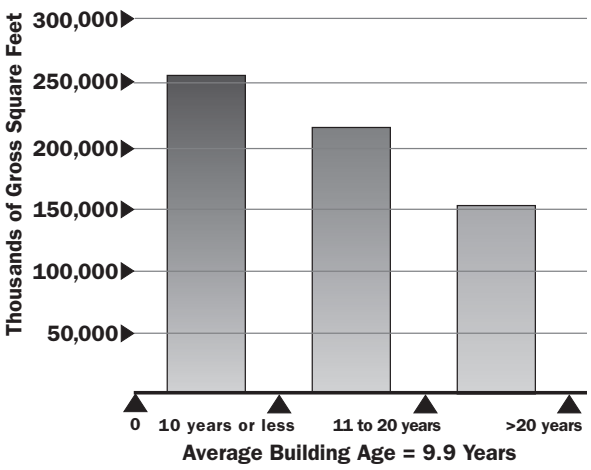


Figure 22.
Age of NREL Laboratory Buildings

	Acquisition Cost	Replacement Value	Approximate Annual Investment Required		Average Annual Investment Last	Ref #
			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%	$3.7	5
Total NREL Assets	$126	$185	$11.5	6%	$5.5	

Table 4.
Value of NREL Assets and Sustaining Investments Required
(dollar amounts are in millions)

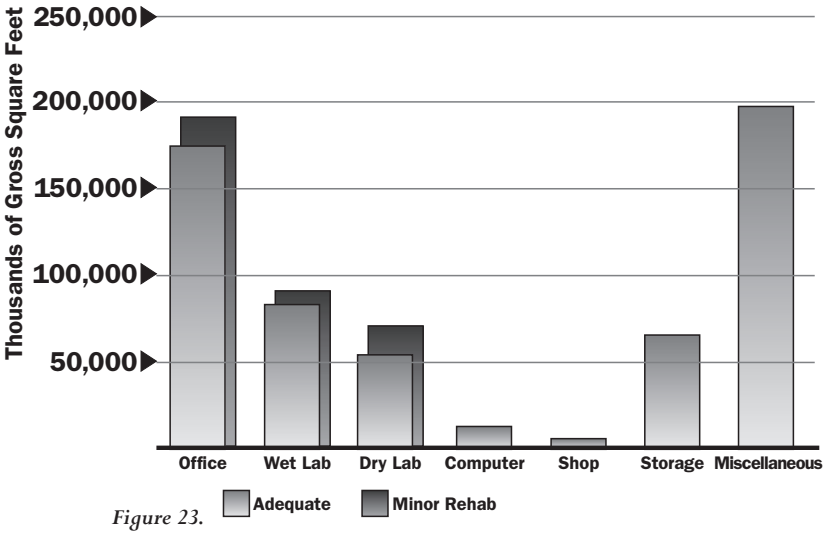


Figure 23.
Use and Condition of Existing Laboratory Space

Aging and obsolete scientific instrumentation is more prone to break down, slowing research progress and sometimes forcing NREL to use other laboratories elsewhere around the country. Information technology must be replaced even more frequently than scientific instrumentation in order to remain current and compatible with other laboratories and research institutions because of rapidly changing technology systems.

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 50 percent of NREL's staff remains in leased space, including researchers and some laboratories.

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 percent for office space, and 100 percent 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 labora-

tories 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 housing research support personnel continue under review, and leasing will continue until a more cost-effective option is found.

Effects 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 to the most highly sought research candidates. Also, capital 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 one and a half miles from most of the researchers due to lack of space. 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.

Long-term Stewardship

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 percent 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 percent 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 percent 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.

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.

Site and Facilities Investments

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 2003-FY 2007.

The Solar Energy Research Facility was built to house sophisticated research and development equipment for photovoltaic energy research. Researchers enjoy the best one-of-a-kind laboratories for developing record-breaking solar cell efficiencies for polycrystalline thin films. Using a physical vapor deposition system, this researcher fabricates high-efficiency PV cells of thin films of copper indium diselenide.

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.

	FY2001	FY2002	FY2003	FY2004	FY2005	FY2006	FY2007
Infrastructure GPP/GPE	**4.0**	**4.0**	**4.5**	**4.5**	**5.0**	**5.5**	**5.5**
Science and Technology Facility		6.0	7.1				
Field Test Laboratory Building Modifications							
South Office Addition		1.0	3.0				
Northeast Office/Lab/HVAC Additions				4.0			
Distributed Energy Resources Test Facility							
Systems Interconnection Test Lab			3.0				
Hybrid and Systems Test Facility				3.3			
Wind Energy Research Facilities							
Structural Blade Test Facility			0.9	5.1			
Large Dynamometer				1.2	6.8		
Electrical Upgrade				3.0			
National Bioenergy Center Facilities							
Bioenergy Research Facilities Phase I PDU Expansion			4.0				
Bioenergy Research Facilities Phase II TCUF Expansion				0.8	6.0		
Bioenergy Research Facilities Phase IIi Applied Biology Labs				4.8			
Hydrogen R&D Facility					4.8		
Advanced Transportation Facility				1.5	10.0		
Thermal Test Facility Expansion				2.5			
TOTAL CAPITAL REQUEST	**4.0**	**11.0**	**22.5**	**25.9**	**37.4**	**5.5**	**5.5**

Table 5.

NREL Five-Year Construction Plan, FY 2003 - FY 2007

The figures contained in this chart represent NREL's needs for the future as prepared in February 2001 and have not been approved by DOE.

* *GPP = General Plant Projects*
GPE = General Purpose Equipment

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 52,000-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
South Office Addition

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 80 - 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
Northeast Office/Lab/HVAC Additions

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, 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.

Distributed Energy Resources Test Facility

This proposed new facility would be constructed in two phases. In the first phase a 10,000-ft^2 Systems Interconnection Test Laboratory, with room for up to ten

researchers, would be ready for occupancy by the end of FY 2004. This laboratory and adjoining test pads would allow NREL to develop and test the standards and protocols recommended for distributed energy systems. The testing necessary for establishing these electrical standards is a vital need for all U.S. distributed electricity systems regardless of technology or owner. The high-performance office and lab building would be designed to be potentially independent of the electrical grid, generating its own electricity up to 1 MW. Phase 2 would focus on the construction of another 10,000-ft^2 laboratory, adjacent to the first lab, which would house the Hybrid and Systems Test Laboratory. This laboratory would test long-term performance, reliability, and efficiency of distributed energy resources. This facility has a target occupancy date of the end of FY 2005.

Wind Energy Research Facilities
Two new facilities, and an electrical infrastructure upgrade, are planned at the National Wind Technology Center. The Structural Blade Test Facility would augment the existing blade testing facilities and add a small wind tunnel for expanded testing capabilities. The Large Dynamometer Test Facility would be similar to the existing 2.5 MW Dynamometer facility, but about 6 MW— enabling it to meet the needs of future generations of turbines. An electrical upgrade is also required for this facility as the Wind Energy Program studies larger and larger turbines.

National Bioenergy Center Facilities
The goals of the National Bioenergy Center are to develop multiple products — electricity, fuels, heat, chemicals — from biomass residues and natural biomass sources using biochemical, thermochemical, and combined technologies; and, to custom design microbes and biomass — algae, grasses, etc.— using genetic engineering to yield more and better products than natural microbes and biomass. In order to meet our commitments as host to the new National Bioenergy Center, NREL needs to expand several existing facilities. Current biological, chemical, and related laboratory research (and small-scale process development research) is conducted in the Field Test Laboratory Building (FTLB). 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. To support new bioenergy research, expansion of the FTLB and associated laboratories is expected to be carried out in three phases.

Phase I: Alternative Fuels User Facility (AFUF) Process Development Unit (PDU) Expansion. NREL intends to pursue two technical paths to convert biomass into multiple products — biological and thermochemical /chemical. The AFUF PDU has been used for several years to convert biomass into ethanol using various bioconversion processes. NREL proposes expanding the PDU so that it can be used to convert multiple feedstocks into multiple products, such as various sugar platforms to produce biofuels, chemicals, hydrogen, and other products. This project would about double current PDU space and provide an additional biomass storage and processing area.

Phase II: Thermochemical User Facility (TCUF) Expansion. The TCUF (located within the FTLB) has been used for several years to convert biomass into

various products using thermochemical and chemical processes. NREL proposes expanding the capabilities and size of the TCUF so that it can handle a greater variety of processes and produce a wider range of products, including biogas, other fuels, power, chemicals, and hydrogen. This project would add a 9,000-ft^2 high-bay addition, including special areas for hydrogen production and additional biomass storage and processing.

Phase III: Applied Biology Labs Expansion. Custom designing microbes and biomass to yield more and better products requires biotechnology laboratories. NREL proposes building out the remaining 9,000-ft^2 of laboratory spaces within the FTLB through this project to support this expanded research. This would add biochemistry and genetic engineering laboratories necessary to yield more and better products compared to natural microbes and biomass.

Hydrogen R&D Facility
As hydrogen research moves from the laboratory to a process testing environment, a suitable process R&D facility will be needed. This 6,000-ft^2 laboratory would be constructed to handle testing of fairly large quantities of hydrogen, and perhaps also natural gas, in conjunction with hydrogen use in fuel cells and other conversion technologies.

Advanced Transportation Facility
Transportation research for advanced vehicles and fuels currently shares space with buildings energy research in the Thermal Test Facility. Both programs need more space. This 40,000 ft^2 facility would support the current and future advanced vehicles and fuels research done onsite at NREL, and would be available to U.S. industry for sharing research.

Thermal Test Facility Expansion
NREL currently has a 6,000-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 60 percent in floor space.

Illustrating the environmentally friendly aspects of renewable energy, a deer herd peacefully coexists with NREL solar test facilities on top of South Table Mountain.

Integrated Safety Management

As a DOE national laboratory, NREL takes the safety and environmental wellbeing 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 a 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 on 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 have necessary ES&H qualifications.

Workers take part by developing and following safe operating procedures (SOPs), by complying with safety rules and regulations, by making sure they attend periodic training classes, and also by 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 wellbeing of others.

Finally, the ES&H Office acts as coordinator and implementer of all ES&H policies. It develops the ISM Program, implements it, and provides 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 achieved full implementation of its ISM Program in May 2000.

Information Management

In FY2000, the Laboratory completed the three-year Information Technology Architecture Initiative (ITAI). The ITAI consisted of 18 integrated IT-focused projects aimed at fundamentally improving the Lab's information technology platform. These improvements, which will form the foundation of the Lab's next generation IT environment, ranged all the way from upgrading the wiring in the walls to redesign of the Lab's core business applications — and enhanced each of the Lab's unique computing environments.

Highlights of the improvements include:

- Installation of new wiring and interconnectors upgrading over 80 percent of the Lab's existing wiring
- Implementation of a more efficient network design, replacing an ineffective and outdated schema
- Adoption of an integrated suite of client-server business systems
- Y2K assessment, testing and certification for the Lab's business systems
- Replacement of multiple stove-piped email systems with a single, Lab-wide messaging system
- Installation of remote desktop configuration and support systems for both Macs and PCs, providing asset management, remote diagnosis and repair, inventory and software distribution
- Adoption of a Lab-standard suite of core office-productivity applications, establishing common formats for the interchange of data throughout the organization
- Technology refresh of the Lab's desktop computers (PCs and Macs).

As the Lab enters the new millennium, it is clear that information technology will play an increasingly pivotal role in all aspects of the Lab's mission. 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 rapid evolution of technology and culture.

The scientific and technical computing environment is already beginning to leverage the increased stability and bandwidth resulting from the ITAI investments. During FY 2001, the Lab began work on the development of dedicated computational science infrastructure, including high-end workstations for visualization and computation, dedicated storage for scientific data, increased internal bandwidth to facilitate the movement of large data sets, and new connectivity to external resources to promote and enhance scientific collaboration. Computational science is one area in which the Lab expects to see benefit from the utilization of information technology. Enhanced inter-Lab (and Lab-to-industry) scientific collaboration, via 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 productivity, collaboration and knowledge management environment is poised for explosive growth as more and more of the Lab's intellectual capital is captured electronically. Over the next five years, there will be an increasing emphasis on document management and retention as the challenge of deciding what to retain and what to delete becomes more important. The Lab's primary conduits for knowledge will continue to be it's messaging system and it's intranet — and these will continue move towards each other — resulting in seamless integration.

The Lab's business management environment will continue its evolution toward a Web-centric model. Following industry trends, the Lab's investment in Oracle as the core for our integrated applications enables expedient migration to Web-based access. Web access to systems enables NREL to be more efficient and effective, capturing data at the point of origin — whether it be an employee changing their address or an electronic purchasing transaction. NREL is aggressively pursuing the Web-centric model, and in the next year, with the upgrade to the next release, will no longer have a client-server tier for business systems.

Additionally, NREL's strategy for data warehousing provides the flexibility to respond to requests for information quickly and accurately. NREL continues to develop this capability via plans for a Human Resources data warehouse.

NREL's information technology infrastructure will become more secure, while at the same time, extending its reach beyond

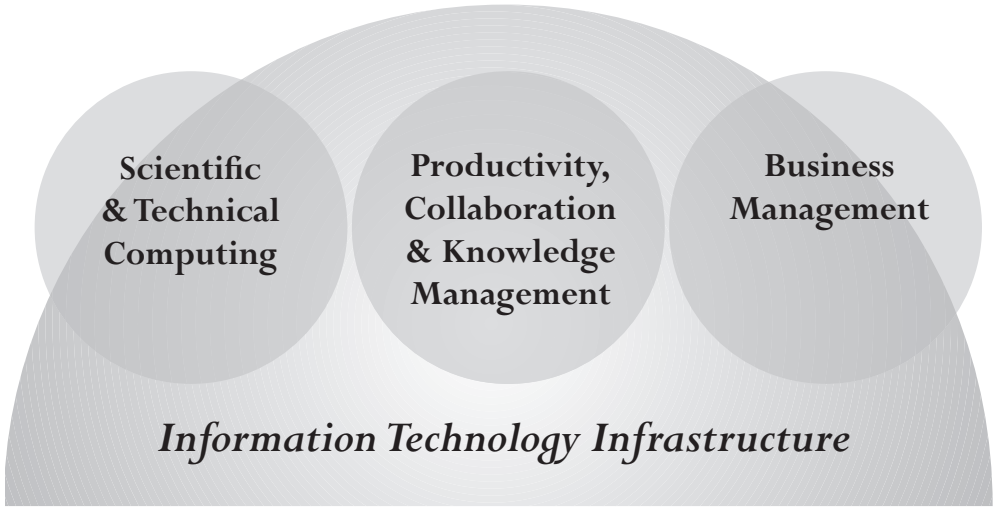


Figure 24.
Information Technology Infrastructure
NREL's three major computing environments are supported by a fourth — the underlying Information Technology Infrastructure.

the Lab's physical boundaries. The expected growth of consumer broadband access will open up new opportunities for remote access, supporting even bandwidth-intensive applications like audio and video. At the same time, the Lab will face even more stringent requirements for protecting its information technology assets from harm. The challenge for the Lab will be to find the right blend of end-user flexibility and organizational stability and security.

Internally, Laboratory will see continued demand for bandwidth (both across the LAN, and to the Internet), and for data storage. Bandwidth demands will continue to grow as new applications play leapfrog with available capacity. As files grow in complexity, they will grow in size, and the Laboratory will seek out new ways of managing the growth of electronic data.

Consistent with these envisioned changes, the Lab's five strategic goals for its computing environments continue to focus on supporting and enabling the Lab's critical outcomes through the application of information technology.

These five goals are:

- 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 and Technology 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

This CLOUT (NREL's after school reading and science program) volunteer helps an elementary school student with a kaleidoscope science project.

NREL's Science and Technology Education Programs office 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 the following three overarching goals.

Develop a Capable, Diverse Workforce

NREL's Science and Technology Education programs reach students at all levels. Included are tutoring of and hands-on science activities for young students in after-school programs, such as CLOUT (weekly after-school reading and science program). For middle school students, NREL sponsors special events, such as the Junior Solar Sprint (model solar car competition) and Expanding Your Horizons (hands-on science workshops for young women). NREL sponsors awards and provides recognition for secondary students at the Colorado Science and Engineering Fair through the "Renewable Energy and Energy Efficiency Award" and conducts DOE's Science Bowl competition.

Undergraduate 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 Energy Research Undergraduate Laboratory Fellowships (ERULF) and the Community College Institute (CCI) are instrumental in encouraging students to explore careers in renewable energy and energy efficiency.

Expanding Your Horizons introduces middle school young women to successful female role models in hands-on workshop settings.

Middle school students build their own solar cars using PV modules and electric motors and then race their cars during the Colorado Junior Solar Sprint at NREL.

Contribute to Excellence in Teaching and Learning

NREL contributes to improving the education system so that 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, research participation opportunities and renewable energy workshops are offered to teachers to enhance their content knowledge, instructional strategies, and leadership abilities. NREL supports teachers in schools with large populations from underrepresented groups, such as ethnic minorities and young women. Some of the teacher research programs and workshops include: Teacher Research Associates (TRAC) Program, Pre-Service Teacher (PST) Training Program, and teacher workshops on photovoltaics.

NREL also engages in partnerships and collaborations with education organizations, such as the Colorado Mathematics and Science Education Coalition and the Utah, Colorado, Arizona, New Mexico rural Systemic Initiative to improve science, mathematics, and technology education.

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 use 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. An example is the DOE-sponsored Texas Southern University's (TSU) summer academy for high school students. As part of the academy, NREL provides a comprehensive program that blends the renewable energy content the students learn at TSU with hands-on application of the technologies during a weeklong course at NREL. Universities and NREL engage in joint research projects; faculty and postdoctoral fellowships and sabbaticals; adjunct faculty arrangements; scientist-faculty exchanges; and, facility access, use, and sharing.

Dr. James Momoh of Howard University leads his photovoltaic research team in the PV measurements laboratory.

Research Participant Program summer students pose at the National Wind Technology Center.

Intellectual Property and Technology Transfer

One of the cornerstones of NREL's mission is to facilitate the commercialization of energy efficiency and renewable energy technologies, implying that NREL has a uniquely intimate relationship with its industrial and R&D stakeholders. While there are many mechanisms and approaches to establishing and maintaining effective relationships, Laboratory technology transfer activities are among the most powerful. Vehicles for technology transfer include subcontracts, cooperative research and development agreements (CRADAs), work-for-others agreements (WFOs), and licenses with industrial partners; dissemination of technical results and know-how through publications and Web sites; exchange of ideas through participation in conferences and workshops; and outreach and training activities. A summary of technology transfer activities at NREL for FY 2000 is given in Table 6.

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 within the Laboratory and with partners. This task draws from the functional concepts, copyrighted works, inventions, and patented ideas that come from NREL scientists. To properly develop and transfer technology in a way that protects the interests of NREL, its partners, and DOE—and that maximizes benefits to the consumer—the Laboratory shepherds candidate concepts through U.S. and international patent processes, develops commercialization strategies, and engages in a variety of outreach activities with the energy industry to define and implement pathways to transfer Laboratory intellectual property to the private sector.

With greatly improved economics for many technologies in NREL's intellectual property portfolio, along with accelerating implementation of policy initiatives favoring clean energy technologies, NREL is witnessing ever increasing demand for access to its patented technology. The interest from the marketplace is now global, and NREL will respond by putting in place enhancements to its intellectual property management, marketing

	FY1997	FY1998	FY1999	FY2000
Inventions	36	49	51	53
Patent Applications	19	18	34	34
Licenses	1	3	7	7
CRADA / WFO / ASA*	3	25	48	29

Table 6.
Results of NREL Intellectual Property and Technology Transfer
** Cooperative research and development agreements, work for others, and analytical service agreements — direct ways in which NREL transfers technology and know-how to others.*

and licensing activities. The Tech Transfer Web site will be improved and expanded to afford better access to technology information by industry and academia. Through greater interaction with other DOE labs, NREL is examining the potential to package its intellectual property with that from other DOE labs to provide greater total value to industry. We are also examining other leveraging opportunities such as contractor-funded technology transfer and user facilities.

The deregulation and restructuring of the electric utility industry, coupled with growing environmental concerns, is creating unprecedented opportunities for new clean energy companies. Power companies are investing in emerging energy companies at an unprecedented rate, and many investors claim there is more money available than good investment opportunities. But lessons learned in industry growth forums held by NREL indicate that many clean energy companies lack the market focus necessary to succeed in the competitive marketplace. In particular, many firms wait too long — well into the technology validation process — before paying serious attention to business planning, marketing strategies, and customer development. Generally, these firms want and need strong business and financial advice and a more complete management team.

To help remedy this situation, NREL is leading the development of a National Alliance of Clean Energy Business Incubators to provide an array of business and financial services to clean energy entrepreneurs. Business incubators have played an invaluable role in the rise of the economy, providing unparalleled access to business networks, mentoring, and venture capital. High-quality incubators have been proven to increase the chance of a start-up's success by helping to fill enterprise development needs and immersing the entrepreneurs in a "business formation" environment. This environment includes support and expert advice in areas such as:

- Instituting and maintaining balance between market and technology development
- Developing a robust strategy for a sustained competitive advantage
- Identifying management team additions.

Alliance members foster technology venturing by linking public-sector initiatives with private-sector resources and leveraging relationships with investors, and industry and financial experts. Alliance members include business incubators interested in adding clean energy companies to their portfolios, and a broad portfolio of new companies involved in clean energy technologies including renewables, micro-turbines, fuel cells, power quality, energy efficiency, alternative fuels, and energy related information technologies. The current partners in the National Alliance of Clean Energy Business Incubators include five successful business incubators in Texas, California, Florida, and Massachusetts, and the alliance will be expanded to more states in the future.

Director's Discretionary Research and Development Program

DDRD projects — monolithically integrated PV modules for dish solar concentrator systems.

DDRD projects — solar-grade polysilicon feedstock development.

DDRD projects — anistropy in hydrogenated thin-film silicon materials.

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 Program is closely integrated with the Laboratory's key technical thrusts for the future. For the next five years this includes bioenergy, distributed power and hybrid generation, carbon management, energy analysis, nanotechnology, collaborative international opportunities, and computational science. The 33 projects active in FY 2000 addressed a wide range of strategic research topics including bioenergy, biotechnology, and chemistry (40 percent of the projects), advanced materials for renewable energy technologies (33 percent), advanced measurement and characterization techniques (9 percent), distributed and hybrid energy systems (9 percent), energy efficiency technologies (6 percent), and energy analysis (3 percent).

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. There were many noteworthy outcomes of recent DDRD projects, including:

- The successful adaptation of the techniques of near infrared and pyrolysis molecular beam mass spectrometry for use in screening biomass samples for characteristics important to biotechnology applications.
- 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*.
- Development of techniques to slow down the chemical reactions of organic radicals and study the role that the radicals play in oxidizing hydrocarbons. This is a capability unique to NREL and is important for investigating fuel combustion and the environmental processes of pollutants in the atmosphere.

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

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

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. Some of the initiatives are provided for consideration by DOE, and their inclusion in this plan does not imply DOE's funding approval or intent to implement them as initiatives. Other initiatives have been approved, but are in the early formative stages of planning and so are included here.

The Initiatives

Bioenergy

Distributed Power and Hybrid Generation

Carbon Management

Enhanced Analysis

Nanoscience and Nanotechnology

International Collaborations

Computational Science

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 indigenous 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. Broader use of biomass has the potential to create new income for farmers while partially addressing the problem of excessive carbon dioxide emissions to the atmosphere.

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. In October 2000, the U.S. Department of Energy announced the creation of a National Bioenergy Center, to be located at NREL and led jointly by NREL and the Oak Ridge National Laboratory. This Center will link DOE-funded biomass renewable energy research programs with the resources and capabilities of the U.S. Departments of Agriculture and Interior, the Environmental Protection Agency, the National Science Foundation and several other federal agencies, DOE laboratories and universities.

NREL has an extensive biomass research program focused on conversion of biomass feed stocks into electric power, transportation fuels and chemical products. Oak Ridge is the leader in the development of biomass feedstocks for energy production. The National Bioenergy Center will be the focal point for technology development and information about bioenergy in the United States, giving industry a focal point for access to world class research and state-of-the-art national laboratory facilities as well as universities.

The Center is modeled after the National Center for Photovoltaics and the National Wind Technology Center located at NREL — capitalizing, as those Centers do, on the assets of several DOE laboratories to collaboratively support and advance renewable energy research and development. An integrated national effort can spur innovative new products, new markets and new techniques that will make the U.S. a world leader in production of bio-based energy and products.

Specifically, the National Bioenergy Center is expected to:

- Integrate strategic and multi-year planning to assure optimum use of government laboratory, university, and industry resources
- Leverage integrated research, development and demonstration across multiple organizations and agencies
- Provide coordinated access to existing capabilities in support of DOE objectives
- Provide process and life-cycle analyzes
- Provide a center for data and information
- Provide technical assistance to industry and universities.

An NREL researcher views a DNA sequencing gel of the gene that codes for acetyl-coA carboxylase. Gene mapping is key to producing clean-burning transportation fuels.

The strategy for Bioenergy is two-fold: To develop multiple products from biomass residues and natural biomass sources, and to custom-design biomass through genetic engineering to yield more and better products than natural biomass.

The petroleum industry began as a single product industry (kerosene), and now makes fuel gas, liquefied petroleum gas, gasoline, naphtha, diesel fuel, lube oils, jet fuel, coke, fuel oils, asphalt, and petrochemicals. Similarly, biomass for bioenergy began as a single product (wood or other biomass burned for heat) will in the future make heat, electricity, ethanol, biogas, other fuels, charcoal, chemicals, plastics, fertilizer, pesticides, and other products. This multiproduct focus will accelerate the transition to a viable bioenergy industry and get the most value from all biomass resources. And unlike petroleum, biomass can be designed for tailored products and energy. Through genomics, genetic engineering and information science, plants can be grown that will less energy-intensive conversion processing to get to the desired products and energy.

The National Bioenergy Center will focus on specific R&D advances needed to carry out the multiproduct strategy. Among these are:

- Innovative biomass materials handling
- New crops and combined processes for multiple products
- Higher specific activity cellulase enzymes to produce sugars leading to many different products
- Lignin chemistry and utilization
- Syngas production followed by conversion to higher value products
- Catalytic ammonia, power, and fuels coproduction for on-farm fertilizer and energy production.

In addition, the National Bioenergy Center will address R&D advances needed to carry out the designed biomass strategy. These include:

- Plant cell wall variability
- Genetic control of physical and chemical properties of plant cell walls
- Genetic mapping of selected crop species
- High-value chemical production potential of designed crop plants
- Biodiesel and carbon fixation in diatoms.

Using a continual shrinking bed counter current reactor, designed by NREL researchers, lignocellulosic biomass is totally hydrolysized, using very dilute acid, for ethanol production.

Distributed Power and Hybrid Generation

In the rapidly changing arena of electricity and power in the United States, NREL is involved in distributed generation (producing electricity through photovoltaic modules, wind turbines, fuel cells, geothermal systems, microturbines, advanced turbines, reciprocating engines, and combined heat and power systems), distributed power systems (local distribution, storage and interconnection of electrical systems), and distributed energy resources (DER, local supply and demand-side measures and infrastructure to deliver electricity). In the context of systems, distributed generation is embedded in distributed power which in turn is embedded in distributed energy resources.

NREL has been working with DOE and external stakeholders to evolve a strategy for distributed power systems and now DER systems. DER development supports national goals such as supporting the formation of competitive electric systems, increasing energy efficiency, and ensuring electric system reliability, flexibility, and emergency response capability. In particular, DER 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. DER also has the potential to provide environmentally cleaner generation options. These aspects of DER are key factors in the focus of the Office of Distributed Energy Resources in the DOE Office of Power Technologies, with which the NREL initiative is coordinated.

A major thrust of NREL's mission is to facilitate the use 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. Used as a DER 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. And the benefits of DER are most valuable when used in "full value" markets, where the distributed energy resources owner, through either contractual or regulatory arrangements, realizes the full value of direct local benefits to the energy consumer, and also the full economic value of the additional benefits created for the local grid.

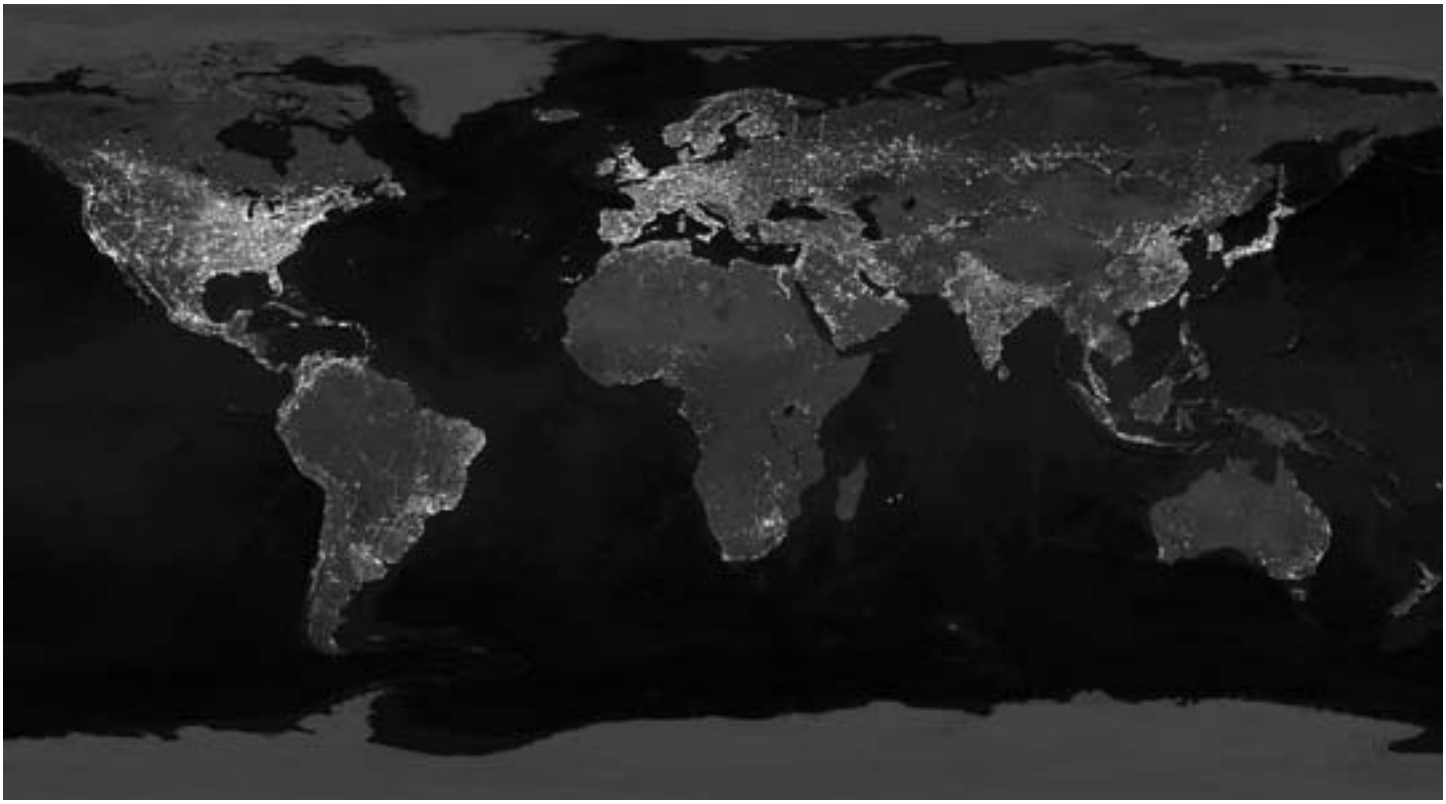
Natural gas is predicted to be the primary fuel for new electricity generation additions in the United States for the foreseeable future. Combinations of natural gas and renewable generation systems — hybrids — bring many additional benefits, such as increased environmental benefits compared to natural gas alone, and a compensation for the intermittency of renewables.

Consequently, NREL's vision is that hybrids of natural gas and renewables can result in superior generation products by combining the advantages of both energy resources. Furthermore, used as distributed energy resources, renewables and hybrids would enjoy the competitive advantage of serving high-value markets.

As an illustration of rapid technology advancement in proton-exchange membrane fuel cell technology, the new cell on the right can generate 13kW of electricity as compared to the previous generation (left) at 5 kW of power.

NREL strives to:

- Enhance its current capabilities to bring greater support to DOE in the development of universal electric-grid interconnection standards for distributed power systems
- Define the needs for various types of testing capabilities and facilities to develop and validate interconnection testing methods for universal electric grid interconnection standards in a controlled environment
- Develop an expanded renewable/fossil hybrid systems test capability to test their performance in village power and urban grid-connected/power park applications
- Establish NREL as a focal point to develop and maintain consensus uniform protocols for DER systems field and lab testing; coordinate test missions to optimize the value of DER testing at various sites across the United States, and analyze and disseminate test results to appropriate stakeholders
- Extend existing NREL models to enhance our ability to analyze distributed energy systems.



Growth in electricity demand is stressing transmission, distribution, and generating capabilities in industrialized areas. Distributed and hybrid technology options are key solutions for the future.

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 stabilizing atmospheric concentrations of carbon dioxide 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 low-carbon 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. We are expanding 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. NREL is developing collaborations with other national laboratories, federal agencies, and academic institutions where NREL's expertise and capabilities logically fit into larger program efforts.

The synthesis of inorganic catalysts are used in the electrocatalytic reduction of carbon dioxide to methanol.

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. Yet another way 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.

NREL is exploring carbon dioxide as a resource, stimulating research opportunities in areas that complement energy production or energy efficiency. Specifically, NREL will:

- Research the basic processes involved in the emission of greenhouse gases produced both naturally and anthropogenically
- Research the use of solar driven conversion of greenhouse gases into fuels and products including novel approaches for direct recovery of CO2 from the atmosphere
- Research biological systems that produce alternatives to carbon based fuels such as hydrogen.
- Develop analysis tools (experimental and systems) to evaluate various processes, mechanisms, or schemes involved in managing anthropogenic sources of greenhouse gases

- Research 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.

NREL designed and built this recirculating system for the study of photochemistry in supercritical carbon dioxide.

Enhanced Analysis

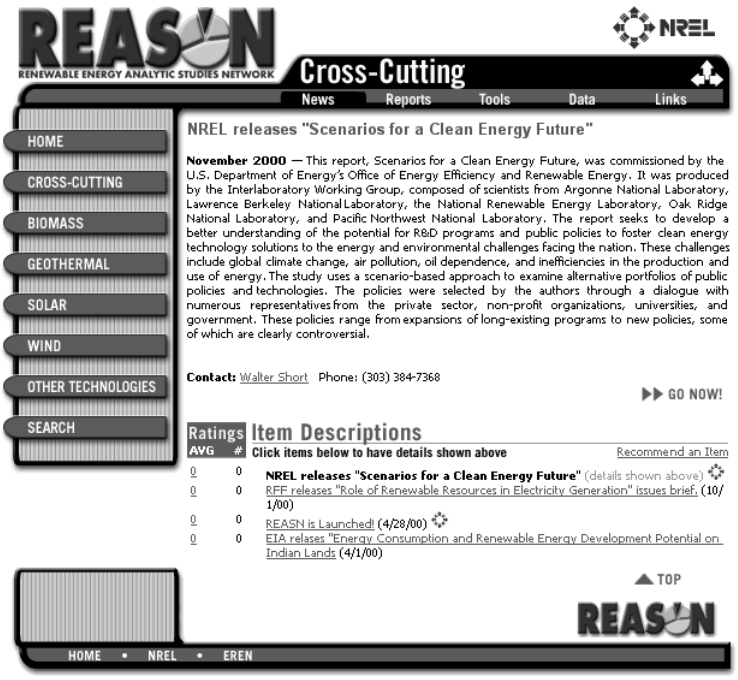
NREL is pursuing a strategy to strengthen its current analysis capabilities to enable the laboratory to address the increasingly complex program and policy planning and management needs of DOE and NREL. NREL's overall goal is to develop and provide the nation with an energy analysis center of excellence comparable to our several national technology centers, such as the National Wind Technology Center and the National Center for Photovoltaics.

One key component of that strategy is to expand our relationships with institutions recognized for their superior analysis capabilities. The process of establishing these collaborations is underway and initial collaborative analysis efforts will begin in FY 2001.

A second key component is the development of an Internet platform to enhance the execution and communication of energy analyses using the best available databases, tools, and transparent methodologies. The system will make these analyses broadly available to stakeholders to enable peer review of methods and dissemination and discussion of results. This activity has been integrated with Web-based EERE program database development at NREL.

Thirdly, NREL will lead a Renewable Energy Analysis Forum in FY 2001 that will pull together leading analysts from government, universities, and industry to discuss energy analysis topics, and analysis tools and methods. This forum will discuss recent and current energy analyses with energy program managers and decisions makers and discuss priorities for future clean energy analysis activities. The plan is to continue this as an annual forum focused on clean energy analysis, drawing on lessons learned in this first year to make the series more valuable to DOE and the nation over time.

A fourth part of our analysis strategy is to initiate through broad, collaborative discussions, a series of global and domestic clean energy scenarios through interactions with stakeholders in the U.S. and abroad. These scenarios will be developed and revised every few years. They will focus on portraying the potential roles of renewable energy and energy efficiency in future energy economies, as well as the technology, market, and policy conditions associated with those roles.



The Renewable Energy Analytic Studies Network serves as a platform for many analysis applications.

Nanoscience and Nanotechnology

Nanotechnology involves controlling matter at the atomic or molecular level — building things the way nature does, atom by atom and molecule by molecule. Nanotechnology is being touted as nothing short of the next Industrial Revolution, and a key to future innovations in the economy. A vast flood of recent results in nanotechnology have served to convince scientists and government planners that the right tools, understanding, and mindset have come together to launch a major government initiative in this area. The government's thrust is supported by all agencies that provide funding for science and technology, including DOE, National Science Foundation, Department of Defense, National Institutes of Health, National Aeronautics and Space Administration, National Institute of Standards and Technology. A recent report by the National Science and Technology Council describes this new national program, and DOE recently expressed its interest, rationale, and plan for participation in a plan entitled *Nanoscale Science, Engineering and Technology Research Directions*. DOE received $35 million in new funding in FY 2001 for this program.

NREL has recognized the importance of nanoscience for many years and its potential impact on advancing renewable energy technologies. NREL researchers were among the very first scientists to conduct basic research on nanosized semiconductor quantum dots, and they published one of the first papers on this subject in 1984. Subsequently, NREL researchers have published over 175 peer-reviewed publications in theoretical and experimental nanoscience; NREL is one of the leading DOE laboratories in this field.

One important technology area that could benefit from advances in nanoscience are ultra-high efficiency solar cells that based on semiconductor quantum dot arrays; such quantum dot solar cells offer the possibility of doubling the theoretical efficiency for converting solar radiant energy into electricity or into solar fuels. Another application is to use nanocrystalline precursors to form various types of electronic materials more cheaply and at lower temperature; these electronic materials include thin-film photovoltaics, advanced battery and fuel cell components, and electrical contacts to electronic devices and PV cells. Other applications for nanoparticle precursors include new efficient catalysts, combustion additives, coatings, and lubricants.

Another area that has benefited from the integration of basic and applied nanoscience is the development of a new and potentially low-cost solar cell based on the dye-sensitization of nanocrystalline high-bandgap oxide materials. These dye-sensitized photoelectrochemical solar cells show the promise of good conversion efficiency (greater than 12 percent), low cost, and unique optical properties (useful, for example, in power windows where transparency can be traded for conversion efficiency).

NREL is one of the leading research laboratories in the area of carbon nanotubes. This new nanoscale form of carbon (resulting in a recent Nobel Prize for its discoverers) has many important potential applications for efficient hydrogen storage, separations science and engineering (for example, separating CO_2 from natural gas), and fuel cell membranes. NREL has unique capabilities in carbon nanotube R&D, such as having expertise in three different methods of processing.

NREL will continue to devote significant effort to conduct basic research in nanoscience and to apply new nanoscience and nanoengineering to further the development of in renewable energy conversion technologies. In additional to its success in experimental nanoscience, NREL has also developed world-class competence and leadership in the theoretical aspects of nanoscience. NREL is now well-positioned to strengthen its programs in nanoscale science and engineering and use this expertise in support of a broad variety of programs in EERE, SC, other areas of DOE, and other agencies.

Carbon nanotubes hold hydrogen on their surface by adsorbtion and also within the tube structures. This has potential to significantly increase the amound of hydrogen contained over traditional activated carbon materials.

This is a customized analytical instrument designed and build at NREL. The instrument is used for fundamental analysis of electron dynamics and interactions, and for nanoscale characterization.

International Collaborations

Two billion people, or one in three people in the world, 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, including fundamental poverty alleviation. As an ancillary benefit, 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 clean energy technologies internationally.

NREL is developing partnerships among DOE, other federal agencies (e.g. AID, EPA, state) and non-government organizations (NGOs) that will lead to the implementation of clean energy technologies in developing countries. The need for cost-effective, reliable, and environmentally friendly energy in developing countries is greater than ever before. In addition to grid-tied and stand alone applications, the need to implement community-based applications in remote areas of developing countries has emerged as a critical means of addressing basic local needs and facilitating viable economic development opportunities. Countries like India and China, that represent a significant portion of world population, are actively taking steps to address their nations' energy problems, presenting growing and substantial opportunities for renewable energy and energy efficiency. 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, NREL and their international partners not only maintain their international activities, but also expand them. The fundamental interests served by increased international activities are:

- 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 clean energy resource assessment, planning and project development 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 consistent with the objective of creating sustainable business enterprises with the capabilities to implement clean energy projects. Established relationships with US AID (headquarters and missions), the EPA, multi-lateral and bi-lateral lending institutions, the United Nation's organizations, the international NGO community, developing and developed country institutions should serve as a critical asset contributing to the success of efforts to help facilitate international clean energy projects.

One of the primary focuses for NREL's international and environmental initiative is the Technology Cooperation Agreement Pilot Project (TCAPP), which was developed at NREL. TCAPP is also currently engaged in working collaboratively with the DOE Climate Technology Initiative. On behalf of USAID, DOE, EPA, and the State Department, NREL leads implementation of TCAPP to provide a model for executing market-based 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. New work funded by the EPA will also go forward in assessing the co-benefit of clean energy on public health.

NREL assists in training the engineers and technicians with the King Abulaziz City of Science and Technology in the wiring and operation of a data logger for collecting solar radiation data at the Solar Village outside Riyadh, KSA.

Importantly, NREL will also focus on partnerships in clean energy development with AID missions, global resource mapping, and offerings of NREL's rural electrification assessment tools (HOMER, VIPOR and Regional Assessment) and related analysis and training capabilities to international customers. The primary project partnership activity with AID Missions will involve follow-on work supported by AID Manila for assistance in developing the national use of renewables in the Philippines. The global atlas activity will proceed based on the recently announced funding of NREL by the Global Environment Facility (GEF) to support a regional solar and wind resource assessment activity. The rural electrification assessment tools activities will move forward under an agreement with South Africa.

Mozambique President Joaquim Alberto Chissano (left) and seven of his ministers met with NREL Director Richard Truly (right) and NREL's Larry Kazmerski to learn more about renewable energy technologies and how they might be used in his country.

Computational Science

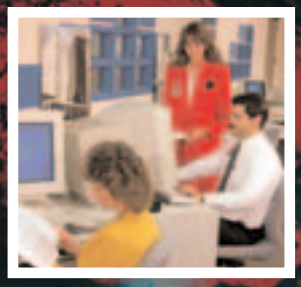
Today most scientific research is accomplished through laboratory experimentation, supported by theoretical studies and to a lesser degree, modeling and simulation. In many scientific venues an increasing amount of science now happens in a virtual environment. Sophisticated software models and exponential increases in computing power now provide a time- and cost-effective platform for much of the scientific process. Government agencies and laboratories are increasing their focus on developing the information capabilities that will best serve our country, and DOE has recognized the importance of scientific computing as a component of several major initiatives (e.g. nanoscale science, bioengineering sciences, carbon management, low/no-carbon energy sources, and sequestration science).

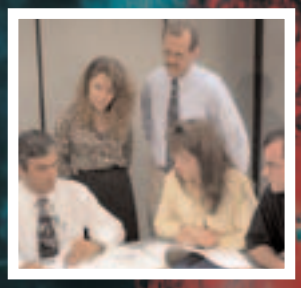
While the possibilities for advances in information technology are vast, the focus at NREL is on using modeling and simulation – computational science – to improve the effectiveness and efficiency of research and to gain insights that may not be possible through experimental techniques alone. Examples of the use of computational science at NREL today include advanced vehicle modeling, wind turbine simulation, materials simulation and property prediction, thermal modeling of buildings and industrial machine components, chemical process modeling, and geographic information systems that model worldwide wind, solar, and biomass resources. In NREL's vision of the future, this type of computational science will become a much more vital tool in the arsenal of researchers in all areas of science and technology.

Advanced computational science paradigms such as virtual experimentation, advanced visualization, and detailed simulation have been proven to revolutionize and accelerate scientific and engineering inquiry. Through the use of supercomputers, terabyte (TB) data sets, and advanced algorithms, researchers can rapidly test and modify vast numbers of research approaches before resorting to costly and cumbersome laboratory experiments and prototypes. Advanced visualization enhances the researchers' understanding of extremely dynamic and complex physical processes that are generated either in the laboratory or by highly detailed computer simulations.

Enhancing NREL's capabilities in computational science will ultimately benefit all of the Office of Energy Efficiency and Renewable Energy program areas, and position NREL to provide cutting edge scientific research with lower cost. NREL will establish additional key linkages and strengthen relationships with other national labs that are involved in the computational science research arena. NREL is developing a strategic investment plan that addresses the Laboratory's current and future computational science requirements, and identifies potential opportunities in EERE, the Office of Science, and other DOE programs related to NREL's mission that would benefit immediately from a stronger capability in computational science. Investments will be required in both additional computational science experts and in systems hardware, software, and/or leasing arrangements.

Resource Projections





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).

Overall Funding and Personnel

	FY1998	FY1999	FY2000	FY2001	FY2002	FY2003	FY2004
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 7.
Laboratory Funding Summary
($ in millions - BA)

	FY1998	FY1999	FY2000	FY2001	FY2002	FY2003	FY2004
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 Laboratroy Personnel	**806.9**	**807.7**	**826.0**	**841.5**	**885.8**	**930.8**	**951.8**

Table 8.
Laboratory Personnel Summary
(personnel in FTE)

Funding by Secretarial Officer

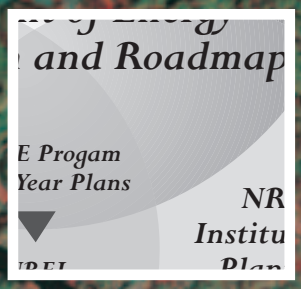
Table 9. ($ in millions - BA)	FY1998	FY1999	FY2000	FY2001	FY2002	FY2003	FY2004	FY2005
Assistant Secretary for Renewable Energy and Energy Efficiency								
Operating	158.7	170.1	172.0	174.5	178.8	183.4	188.0	192.7
Capital Equipment	3.2	1.9	2.3	2.8	2.9	3.0	3.0	3.1
Construction	2.2	0.0	0.0	0.0	15.7	0.0	0.0	0.0
General Purpose Equipment	1.8	1.9	0.8	2.2	2.0	2.	2.6	2.8
General Plant Projects	0.6	2.0	0.4	1.8	2.0	2.5	2.6	2.8
Subtotal Funding	$166.4	$176.0	$175.3	$181.3	$201.4	$191.3	$196.2	$201.3
Director, Office of Science								
Operating	4.7	4.3	4.9	5.0	5.1	5.3	5.4	5.5
Capital Equipment	0.5	0.3	0.5	0.5	0.5	0.5	0.6	0.6
Subtotal Funding	$5.3	$4.6	$5.4	$5.5	$5.7	$5.8	$6.0	$6.1
Arms Control and Nonproliferation								
Operating	1.5	3.2	1.0	1.0	1.1	1.1	1.1	1.1
Capital Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal Funding	$1.5	$3.2	$1.0	$1.0	$1.1	$1.1	$1.1	$1.1
Other DOE								
Operating	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Capital Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal Funding	$0.3	$0.3	$0.3	$0.3	$0.3	$0.3	$0.3	$0.3
Total DOE Funding								
Operating	165.2	178.0	178.1	180.8	185.4	190.0	194.8	199.7
Capital Equipment	3.7	2.3	2.8	3.3	3.4	3.5	3.6	3.7
Construction	2.2	0.0	0.0	0.0	15.7	0.0	0.0	0.0
General Purpose Equipment	1.8	1.9	0.8	2.2	2.0	2.5	2.6	2.8
General Plant Projects	0.6	2.0	0.4	1.8	2.0	2.5	2.6	2.8
Total DOE Funding	**$173.4**	**$184.1**	**$181.9**	**$188.1**	**$208.5**	**$198.5**	**$203.6**	**$208.9**
Work for Others								
40-Reimb. Work for Other Federal Agencies	2.9	3.8	1.5	1.5	1.6	1.6	1.7	1.7
60-Reimb. Work for Non-Federal Agencies	1.1	1.3	0.9	0.9	0.9	1.0	1.0	1.0
65-Cosponsor Supported R&D	0.4	0.7	0.8	0.8	0.8	0.9	0.9	0.9
82-Reconciling Transfers and Others	2.1	1.7	1.5	1.5	1.6	1.6	1.7	1.7
Subtotal Work for Others	$6.5	$7.4	$4.8	$4.8	$4.9	$5.1	$5.2	$5.3
Total LABORATORY Funding								
Operating	171.7	185.4	182.8	185.6	190.3	195.1	200.0	205.0
Capital Equipment	3.7	2.3	2.8	3.3	3.4	3.5	3.6	3.7
Construction	2.2	0.0	0.0	0.0	15.7	0.0	0.0	0.0
General Purpose Equipment	1.8	1.9	0.8	2.2	2.0	2.5	2.6	2.8
General Plant Projects	0.6	2.0	0.4	1.8	2.0	2.5	2.6	2.8
Total Laboratory Funding	**$179.9**	**$191.6**	**$186.7**	**$193.0**	**$213.4**	**$203.6**	**$208.8**	**$214.2**

*The figures for Direct Personnel as FTEs do not include FTEs working on Directors Discretionary R&D, internal recharges for technical support to direct programs, and other research-related activities.
**These statistics give a more thoroughly considered representation of the relationship of research personnel to support personnel, developed as part of DOE's collaboration effort on performance metrics.

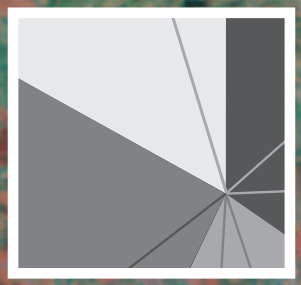
Personnel by Secretarial Officer

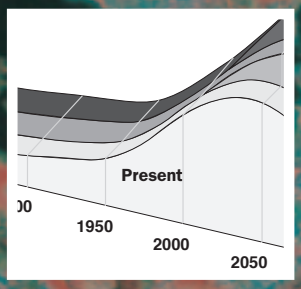
Table 10. (personnel in FTE)	FY1998	FY1999	FY2000	FY2001	FY2002	FY2003	FY2004	FY2005
Assistant Secretary for Renewable Energy and Energy Efficiency								
Operating	357.3	356.5	348.7	348.0	349.0	345.0	340.0	335.0
Capital Equipment	0.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Construction	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
General Purpose Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
General Plant Projects	0.0	0.8	0.6	0.6	0.6	0.6	0.6	0.6
Subtotal	357.7	358.0	350.0	349.2	350.2	346.2	341.2	336.2
Director, Office of Science								
Operating	30.1	26.0	24.7	25.0	26.0	27.0	28.0	29.0
Capital Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal	30.1	26.0	24.7	25.0	26.0	27.0	28.0	29.0
Arms Control and Nonproliferation								
Operating	2.0	2.3	3.0	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	0.0
Subtotal	2.0	2.3	3.0	3.0	3.0	3.0	3.0	3.0
Other DOE								
Operating	3.3	3.5	7.8	8.0	8.0	9.0	9.0	10.0
Capital Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal	3.3	3.5	7.8	8.0	8.0	9.0	9.0	10.0
Total DOE Programs								
Operating	392.7	388.3	384.2	385.0	385.0	385.0	385.0	383.0
Capital Equipment	0.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Construction	0.1	0.0	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	0.0
General Plant Projects	0.0	0.8	0.6	0.6	0.6	0.6	0.6	0.6
Total DOE Programs	**393.1**	**389.7**	**385.4**	**386.2**	**386.2**	**386.2**	**386.2**	**384.2**
Work for Others								
Reimb. Work for Other Federal Agencies	6.6	10.3	9.4	9.8	10.2	10.6	11.0	11.4
Reimb. Work for Non-Federal Agencies	17.8	13.6	11.0	11.4	11.9	12.4	12.9	13.4
Cosponsor Supported R&D	3.0	2.1	4.8	5.0	5.2	5.4	5.6	5.8
Subtotal Work for Others	27.4	26.0	25.1	26.2	27.3	28.3	29.5	30.7
Total Program Effort								
Operating	420.0	414.2	409.3	411.2	412.3	413.3	414.5	413.7
Capital Equipment	0.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Construction	0.1	0.0	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	0.0
General Plant Projects	0.0	0.8	0.6	0.6	0.6	0.6	0.6	0.6
Total Direct Personnel*	**420.5**	**415.6**	**410.5**	**12.4**	**413.5**	**414.5**	**415.7**	**414.9**
Total Indirect Personnel*	**386.4**	**392.0**	**408.7**	**407.0**	**405.0**	**403.0**	**401.0**	**400.0**
Total Laboratory Personnel	**806.8**	**807.7**	**819.3**	**819.3**	**818.5**	**817.5**	**816.7**	**814.9**
Research to Support Ratio**	**2.05**	**1.96**	**2.06**	**2.06**	**2.1**	**2.1**	**2.1**	**2.1**

Appendices

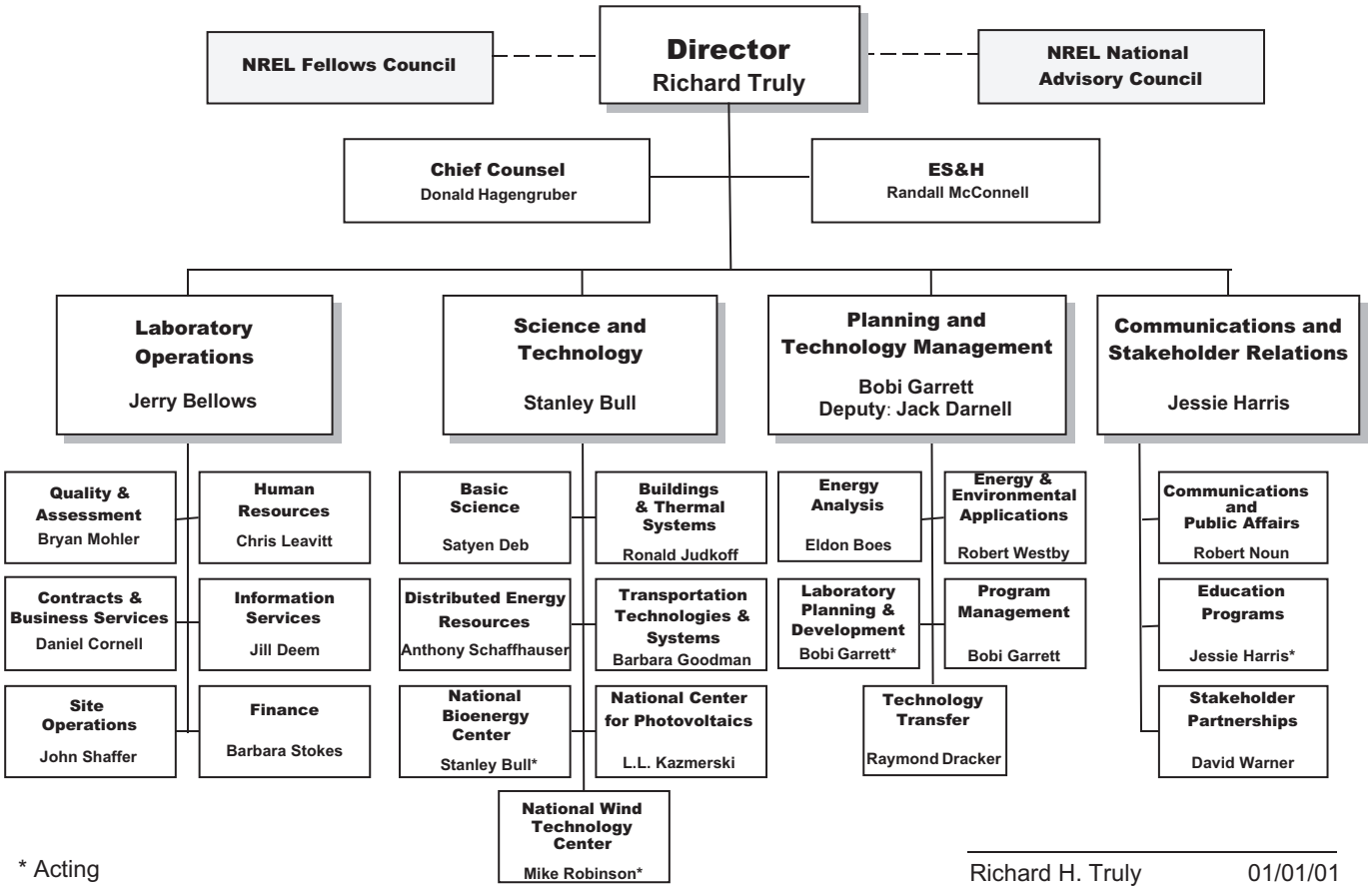


FY1999	FY2000	FY2001
d Energy Efficiency		
170.1	172.0	174.5
1.9	2.3	2.8
0.0	0.0	0.0
1.9	0.8	2.2
2.0	0.4	1.8
$176.0	$175.3	$181.3





Appendix A.
NREL Internal Organizational Chart



* Acting

Richard H. Truly 01/01/01

Appendix B.
Listing of Figures and Tables

Figures

Tables

Appendix C.
Acronym List

ADVISOR	Advanced Vehicle Simulator
AFDC	Alternative Fuels Data Center
AFV	alternative fuel vehicles
AMFA	Alternative Motor Fuels Act
ANL	Argonne National Laboratory
ASHRAE	American Society of Heating Refrigerating and Air Conditioning Engineers
ATV	advanced technology vehicles
BES	Office of Basic Energy Sciences
BIPV	building-integrated photovoltaic systems
BTS	Office of Building Technology, State and Community Programs
CCI	Community College Initiative
CIS	CuInSe2 (copper indium diselenide)
CNG	compressed natural gas
CRADA	cooperative research and development agreement
CRRCI	Central Regional Resource Center for Innovation
CSP	concentrating solar power
DDRD	Director's Discretionary Research and Development
DER	distributed energy resources
DPP	Distributed Power Program
DWOP	Denver West Office Park
EERE	Office of Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPAct	Energy Policy Act
EREC	Energy Efficiency and Renewable Energy Clearinghouse
EREN	Energy Efficiency and Renewable Energy Network
ERULF	DOE's Energy Research Undergraduate Laboratory Fellowship
ES&H	Environment, Safety and Health Office
ESPCs	energy savings performance contracts
FEMP	Federal Energy Management Program
FU	Fuels Utilization Program
GEF	Global Environment Facility
GO	Golden Field Office
HEV	hybrid electric vehicle
HTS	high-temperature superconductivity
HVAC	heating, ventilating and air conditioning
IEEE	Institute of Electrical and Electronics Engineers
IMA	Integrated Motor Assistant
IOF	Industries of the Future

ISM	integrated safety management
ITAI	Information Technology Architecture Initiative
K	degrees Kelvin
LCA	life-cycle assessment
LCC	Laboratory Coordinating Council
LEGO	linear expansion of geometric objects
LIMS	Laboratory Information Management Systems
LNG	liquefied natural gas
mpg	miles per gallon
NCPV	National Center for Photovoltaics
NGO	non-governmental organization
NICE3	National Industrial Competitiveness through Energy, Environment and Economics
OEM	original equipment manufacturers
OIT	Office of Industrial Technologies
OPBM	Office of Planning, Budget and Management
OPT	Office of Power Technologies
ORNL	Oak Ridge National Laboratory
OTT	Office of Transportation Technologies
PNGV	Partnership for a New Generation of Vehicles
PNNL	Pacific Northwest National Laboratory
PURPA	1974 Public Utilities Regulatory Policy Act
PV	photovoltaic
SC	Office of Science
SOP	safe operating procedure
SPI	DOE's Superconductivity Partnership Initiative
STM	South Table Mountain
T1	thallium oxide
TB	terabyte
TCAPP	Technology Cooperation Agreement Pilot Project
TEM	transmission electron microscope
TRAC	Teacher Research Associates
TSU	Texas Southern University
UCB	University of California, Berkeley
UESCs	utility energy services contracts
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WFO	work for others
WindPACT	Wind Partnerships for Advanced Component Technology

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