
NREL
Fall 1995
Science and Technology at the
National Renewable Energy Laboratory
In Review

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Features

Departments

On the cover *— This 275-kilowatt advanced wind turbine is one of several now moving into world markets thanks to government-industry research partnerships (see article p. 3).*

The National Renewable Energy Laboratory

NREL is a national resource committed to leadership, excellence, and innovation in renewable energy and related technologies.

Our research is intended for application in the private sector. We foster cooperation with industry through subcontracts and cost-shared studies. We collaborate with university and industry researchers. Our world-class laboratories are available for experiments, analyses, and proprietary studies.

NREL is a DOE national laboratory operated by the Midwest Research Institute.

NREL In Review

NREL's news magazine is intended to promote the flow of technology from the laboratory to the private sector. *NREL In Review* addresses a readership ranging from scientific professionals to business people. It is distributed without charge to those involved in renewable energy and related fields.

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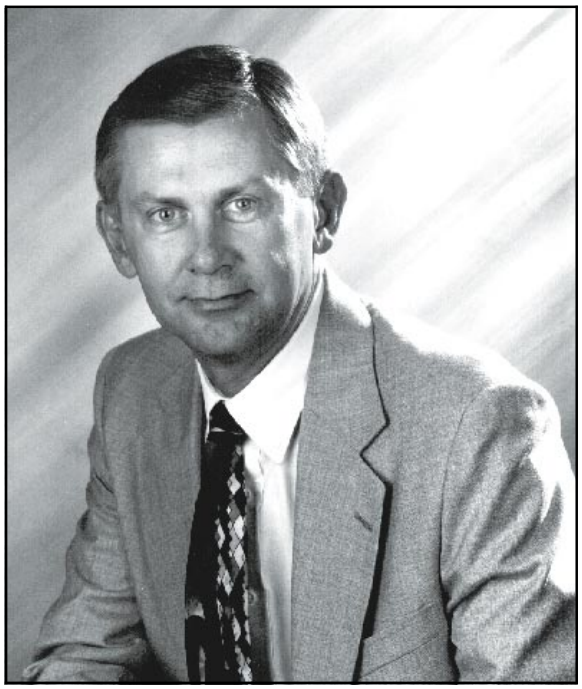


Warren Gretz, NREL

Richard Marczewski,
Manager of Technology and Business Ventures

Forums link companies with financing

NREL's Enterprise Growth Forums are bridging the gap between renewable energy entrepreneurs and the financial community. Held quarterly, the forums allow venture capitalists to become familiar with innovative energy technologies now gearing up for competitive world markets. Growth-stage companies gain access to the advice of seasoned business experts. Forums have been held in Washington, DC, each with more than 60 invited participants from the financing community and the renewable energy industry. The next one is tentatively scheduled for January 1996. For more information, contact NREL's Jessica White at (303) 275-4358.

Meet NREL's new tech transfer manager

NREL welcomes Richard Marczewski as the new manager of its Technology and Business Ventures Office. Formerly the head of NREL's hybrid vehicle program, Marczewski also managed General Motors (GM) Corporation's External Technology Leveraging Group. His duties at NREL include licensing new energy technologies as well as arranging cooperative research agreements and other business ventures. Marczewski holds a master's degree in business administration from Western Michigan University.

Federal Express delivers data

Fleet operators can make better decisions about alternative fuels thanks to an extensive demonstration project conducted with the help of Federal Express and NREL's Fuels Utilization Program. The two-year "CleanFleet" study involved 111 delivery vans operating on M85 (85% methanol, 15% gasoline), compressed natural gas, propane, electricity, California Phase 2 reformulated gasoline, or baseline unleaded gasoline. The vehicles were driven a total of more than 3 million miles in the Los Angeles area.

Among its many results, the study found that electricity and compressed natural gas might offer the greatest reduction in emissions for many fleets. Reformulated gasoline also reduced emissions and did not affect vehicle reliability, although driving range was reduced when compared to unleaded gasoline. The flexible-fuel capability of the M85 vehicles helped overcome limited local supplies of methanol.

Data from this study are available on the Internet by accessing http://www.afdc.nrel.gov or by calling the National Alternative Fuels Hotline at 1-800-423-1363.

Solar radiation data now online

NREL's Steve Wilcox has been working with scientists at the World Radiation Data Center (WRDC) in Russia to make worldwide solar radiation data available on the Internet. Established 30 years ago, WRDC collects, archives, and disseminates solar radiation data obtained at more than 1000 sites. Wilcox went to Russia in 1994 to assist with hardware upgrades. He has also been helping Russian scientists learn more about the World Wide Web and other data distribution technologies. Internet users can access WRDC's data base by entering http://wrdc-mgo.nrel.gov.

PV aids orangutan research

The world's foremost expert on orangutans, Birute Galdikas, is recharging her batteries with a new photovoltaic (PV) system. Galdikas is the president of Orangutan Foundation International, a nonprofit organization aimed at saving the near-extinct primates in Borneo. She and her research team have been using hundreds of batteries every year to provide power for lights and communications equipment, but battery disposal

creates environmental and logistical problems. A group of NREL employees led by John Thornton and Mike Marsh provided Galdikas with a PV system to recharge the batteries for extended use. For more information on the project, contact Mike Marsh at (303) 384-6567.

Benteler looks at vacuum insulation

More efficient catalytic converters may soon be on the market thanks to cooperative research between NREL and Benteler Industries Inc. of Grand Rapids, MI. The company is investigating the use of NREL's compact vacuum insulation for catalytic converters, which Benteler would produce and sell to automobile manufacturers. Catalytic converters wrapped in vacuum insulation would remain at efficient operating temperatures for 17 hours or longer after the vehicle's engine is turned off, thereby avoiding emissions produced by the engine during start-up periods. For more information on NREL's award-winning technology, contact Steve Rubin at (303) 275-4099.

Thermal Test Facility breaks new ground

NREL has broken ground on a new 10,000-square-foot research facility to support development of advanced technology for buildings. The new Thermal Test Facility will house laboratories for advancing research in areas such as ventilation, heating, cooling, passive solar designs, computerized energy design tools, solar water heating systems, and electrochromic coatings for windows. The facility will also be a showcase for energy efficiency, incorporating features such as clerestory windows for daylighting, high efficiency lighting, heat recovery, and direct-indirect evaporative cooling.

NREL captures two R&D 100 Awards

Research and Development magazine has honored two NREL technologies with prestigious R&D 100 Awards, ranking them among the nation's top 100 technical innovations of the year.

The first award went to a breakthrough that simplifies the production of ethanol made from biomass, with significant cost reductions in store. NREL researchers achieved this by genetically engineering the bacterium *Zymomonos mobilis* for more efficient fermentation of plant material to ethanol, a liquid transportation fuel now made primarily from corn. The breakthrough also expands the kinds of feedstocks that can be used to produce ethanol.

The second R&D 100 Award is shared with Coors Ceramics Co. of Golden, CO. The two organizations are developing a novel way to produce high quality ceramic powders at one-third the cost of other processes. Coors is now building a production plant at its Golden facility to meet the expected increase in demand for silicon carbide products, which are used in high-temperature, high-stress applications such as pump seals for refineries and chemical plants.

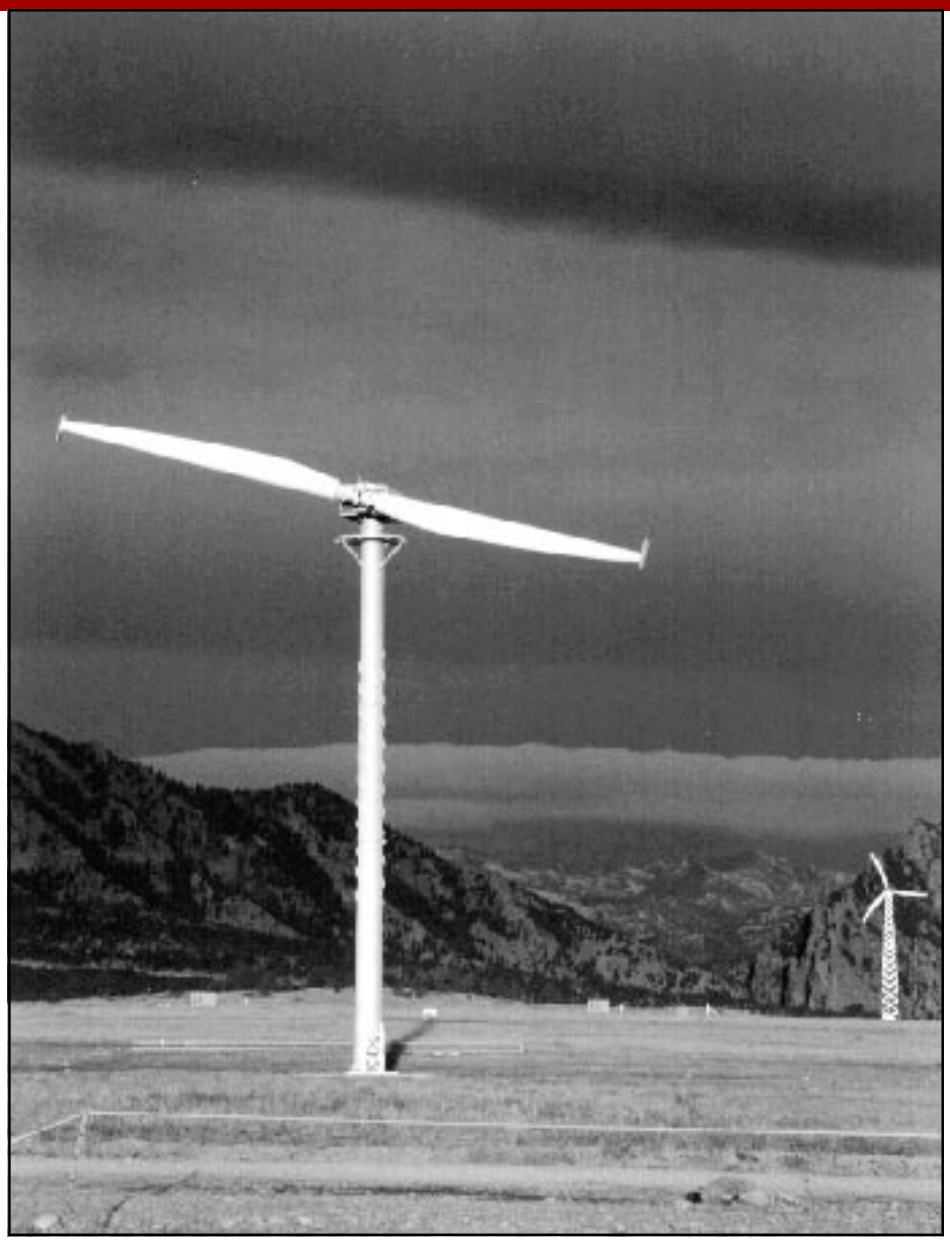
For more information, contact NREL's Technology and Business Ventures Office at (303) 275-3008.

Budget update

At press time, the House and Senate had both approved an energy spending bill that could mean a 25% to 35% cutback in DOE's energy efficiency and renewable energy programs if approved by President Clinton. The impact on NREL's budget is not clear yet.

DOE and NREL are already taking action to reduce operating costs and preserve vital research programs. Energy Secretary Hazel O'Leary has announced the first steps of a budget reduction plan that will save U.S. taxpayers $14 billion during the next five years. The initial steps include consolidating regional support offices as well as fossil-fuel research and development activities. Assistant Secretary Christine Ervin of DOE's Office of Energy Efficiency and Renewable Energy has been participating in an effort to consolidate fossil energy, energy efficiency, and renewable energy programs in a new category—DOE's energy resource business line programs.

NREL continues to develop its three-pronged attack on the budget challenge: improving operational efficiency, creating new business opportunities, and diversifying income. In addition, the Laboratory recently began offering voluntary buyout packages to employees that are expected to reduce staff by about 10%. The results of these initiatives should reduce the impact of federal budget cuts on technologies that are vital to the nation's energy future. ♦



Catching The Trade Winds

With help from NREL, American wind turbine manufacturers are moving advanced machines into competitive world markets

by Robert Ebisch

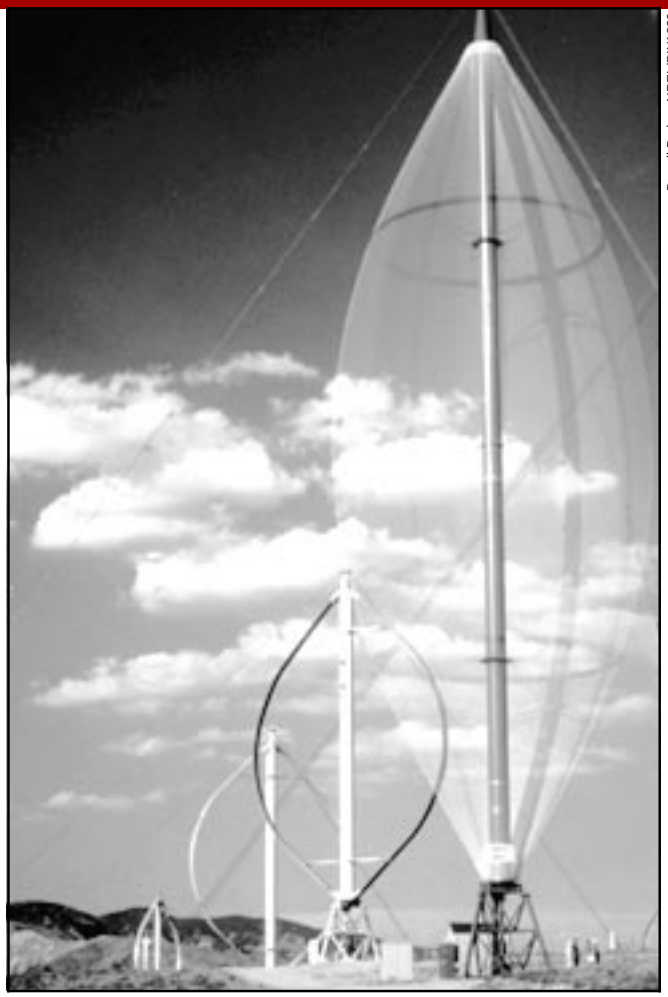
The AWT-27 wind turbine is an impressive sight—and an impressive technology. Spinning atop a 140-foot tower, the turbine's two-bladed propeller sweeps out a circle almost 90 feet in diameter. Lightweight design, sleek blades, simplified mechanical systems, state-of-the-art controls, and aerodynamic braking make this 275-kilowatt machine a serious contender in expanding global markets for renewable energy.

Above: Advanced Wind Turbine Inc.'s new 275-kilowatt machine uses blades designed with advanced airfoils to increase energy production, an innovative teetered rotor to reduce stress from wind gusts, and a strong but lightweight tube tower. (Photo courtesy of Warren Gretz/NREL)

The turbine's manufacturer—FloWind Corp. of San Rafael, CA—is fulfilling a $30-million contract for 220 of its AWT-27 machines. The turbines will be delivered to India, where they will be assembled and installed in a new 50-megawatt wind power plant. This is just the beginning of a multi-year joint venture that could generate orders for an additional $50- to $70-million worth of FloWind machines next year. FloWind also has three projects slated for China, amounting to $160 million in sales and 180 megawatts of new electric generating capacity.

The AWT-27 and the slightly smaller AWT-26 were developed in partnership with NREL through DOE's Advanced Wind Turbine Program with funding from the

> *"Without the collaborative effort, we would not have a product ready for the market today."*
>
> *— Robert Lynette*
> *Advanced Wind Turbines Inc.*



Darrell Dodge, NREL/PIX1829

A new version of FloWind's vertical-axis wind turbine (shown here) will be part of several new installations in China. The new EHD series (extended height to diameter) was developed with assistance from NREL and Sandia National Laboratories.

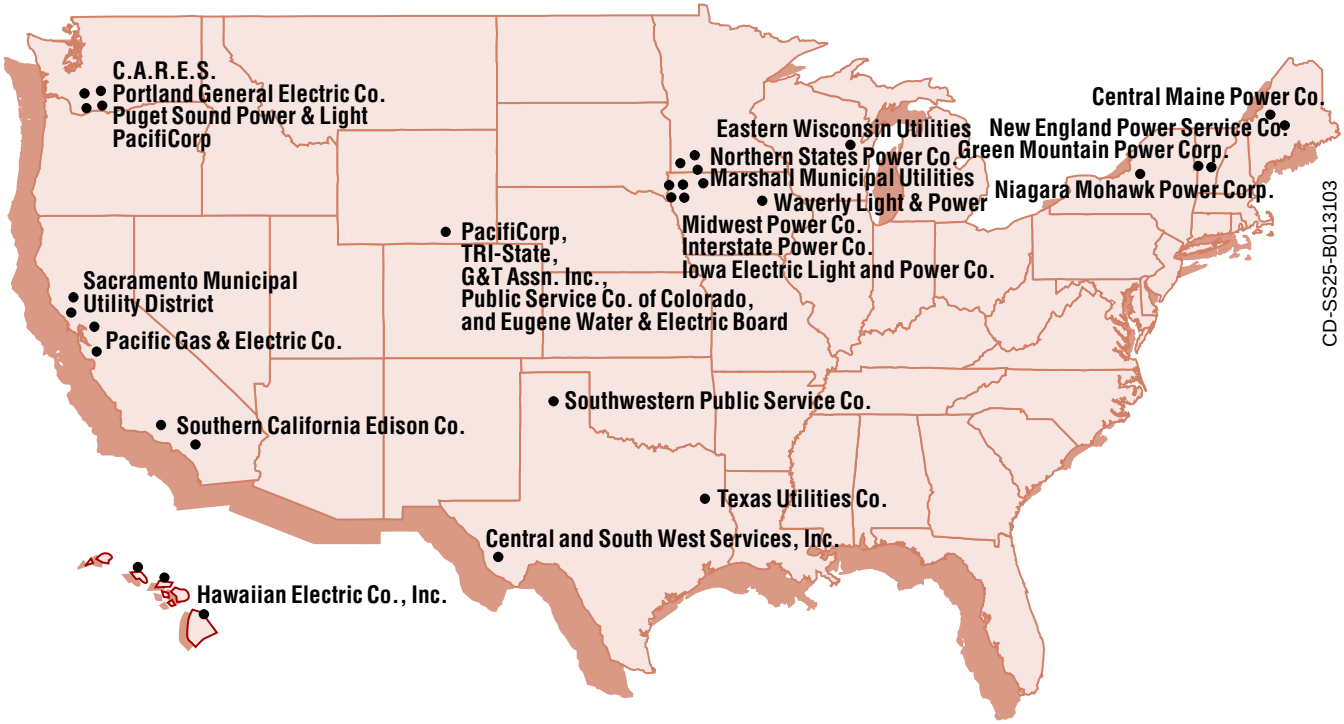
Office of Energy Efficiency and Renewable Energy.

"Without the collaborative effort, we would not have a product ready for the market today," says Robert Lynette, who is marketing vice president of FloWind and president of Advanced Wind Turbines Inc., a turbine manufacturing company owned by FloWind. "NREL has helped us considerably with cost sharing and equally, if not more importantly, with technical support."

Research partnerships with companies such as Lynette's have reduced wind energy costs to about 5¢ per kilowatt-hour in areas with good wind resources. Capital costs have decreased to less than $1000 per kilowatt. But industry experts agree that additional work is needed to give U.S. technologies a leading edge in highly competitive world markets. The next five years are critical to the U.S. wind industry, both domestically and in the huge potential markets of India, China, and Latin America. NREL is helping its industry partners develop advanced machines to meet growing demand.

Moving improved technology into the marketplace

According to the American Wind Energy Association (AWEA), the world's total wind capacity could increase from today's 4000 megawatts to as much as 50,000 megawatts within the next decade. Of the 4000 megawatts in place today,



Utilities across the nation have announced plans to operate wind power plants or to purchase wind power from independent power producers.

about 1700 are in the United States, representing a capital investment of about $3.5 billion. Power purchase agreements now being negotiated or already in place may see another $1 billion investment in U.S. wind capacity before the end of the decade.

In particular, U.S. utilities are warming up to the potential of newly competitive wind power. Some of the wind plants now feeding power to utility grids are owned by utilities; others are independently owned and sell wind-generated electricity as independent power producers. The bulk of U.S. capacity is still in California, where the wind industry began.

"That will be changing over the next few years," says AWEA's Randy Swisher. "Next year there's an additional 100 megawatts going on line in Minnesota and about 50 megawatts in Texas. Between 50 and 100 megawatts will be going on line in the northwest in '96 or '97."

Other wind plant projects, either planned or under way, will serve states such as New York, Vermont, Maine, Michigan, Iowa, and Wyoming. The turbines involved in these projects are not only more advanced but more powerful.

For example, Zond Systems Inc. of Tehachapi, CA, has installed more than 2500 turbines in the 30- to 250-kilowatt range since the early 1980s. Under NREL's Value Engineered Turbine Program, Zond came up with the Z-40, the U.S. wind industry's first 500-kilowatt turbine. The company is installing its new machines in a 6.6-megawatt power plant for Central and Southwest Power near Fort Davis, TX. Zond also won a solicitation with Northern States Power to supply 100 megawatts of wind capacity using the Z-40 and its successor, the Z-46.

"We had wanted to advance the state of the technology for a long time, but the market hasn't been big enough to fund an internal R&D effort such as the one we're pursuing with NREL's help."

— Ken Cohn
Second Wind Inc.

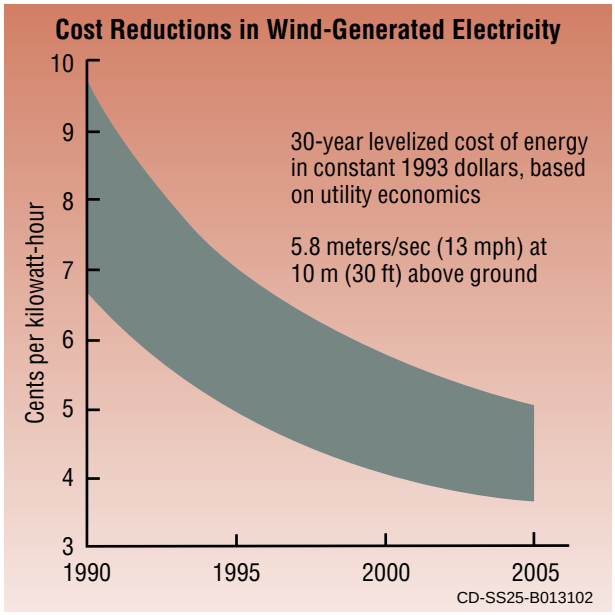
In addition to its work with small U.S. companies, NREL is providing technical support to industry giants such as Kenetech Windpower. Researchers are testing blades for Kenetech's KVS-33 wind turbine, pictured here.

Would Zond have developed the Z-40 without NREL's help?

"I still think we would have developed the turbine anyway, but undoubtedly it would have used different airfoils," says Ken Karas, Zond's president and chief executive officer. "So the machine would probably be somewhat less efficient. The blade testing would have been more difficult to accomplish, and it would have cost a significant amount of money to develop test facilities. Other than NREL, such facilities don't exist in the U.S."

Another subcontractor under the DOE/NREL Value Engineered Turbine Program—New World Grid Power of Palm Springs, CA—is developing a 500-kilowatt turbine dubbed the 500-XST. Sales projections target as many as 100 of these machines by the end of 1996, contingent on prototype performance.

"For so many years, industry product development never came to commercialization," says Clare Lees, president of New World Grid Power. "We think that now the program has taken the direction that NREL and the industry should take."



Wind energy costs now stand at 4¢ to 5¢ per kilowatt-hour and are rapidly declining, thanks to recent technological innovations made by government and industry.

Gearing up for international markets

While domestic markets are warming up, the majority of new wind power installations is expected to occur overseas. For example, Arthur D. Little has projected the installation of 350 to 600 megawatts in China and up to 1200 megawatts in India by the end of the decade.

"Turbines in India tend to be more European in what's installed today," says AWEA's Randy Swisher. "But a number of U.S. companies are there right now putting in new projects."

New World Power Co. (New World Grid Power's parent company) has projects either planned, under development, or in operation in England, Ireland, Wales, Argentina, Costa Rica, Mexico, Nicaragua, Brazil, Guatemala, Chile, China, the Philippines, France, and Turkey.

But compared with the European wind industry, much of the U.S. industry is still in the early stages of development. Cost-sharing and technical assistance are crucial—especially for smaller companies.

"We had wanted to advance the state of the technology for a long time, but the market hasn't been big enough to fund an internal R&D effort such as the one we're pursuing with NREL's help," says Ken Cohn, operations manager for Second Wind Inc. of Somerville, MA. The company is developing a wind turbine monitoring system and wind plant controls with support from an NREL subcontract.

Bergey Windpower Co. of Norman, OK, has been developing a synchronous inverter with technical assistance and joint funding from NREL. Company chairman Karl Bergey compares NREL's seminal role in the wind industry with that of the National Advisory Committee for Aeronautics (NACA), the predecessor of the National Aeronautics and Space Administration (NASA).

"In my view, one of the reasons that our aviation industry leads the world is that NACA, and later NASA, provided important theoretical and practical assistance to the aviation industry from the 1920s on," Bergey says. "The results of NACA's basic and applied research were widely disseminated. Its development facilities—including full-scale wind tunnels—were available to aircraft manufacturers for specific tests. NACA provided a solid foundation for the phenomenal growth of the U.S. aviation industry during World War II and the immediate postwar period. NREL appears to be serving that same function for wind power today."

As wind technology improves, NREL's emphasis continues to change. Five years ago, airfoil design was the most important issue under investigation, and the issue of price-competitiveness appeared to be almost resolved. Now, once again, the big technical challenge is to reduce the cost of wind power. Current technology allows wind plants to produce electricity at rates of 4¢ to 5¢ cents per kilowatt-hour.

NREL-sponsored research continues to probe at the cost issue, reducing costs and optimizing energy outputs with improvements in variable-speed turbines, larger rotors with increased power output, lighter structures, more efficient controls, and simpler components. The results are clearly seen in the marketplace.

"We have our third NREL-supported turbine going into commercialization right now," says Clint Coleman, president of New World Power Technology Co. (formerly Northern Power Systems Inc.) of Moretown, VT. The company has worked under an NREL subcontract to develop its 250-kilowatt turbine, the North Wind 250.

"The contracts for turbine development have clearly been a direct and successful way of getting industry involved," Coleman says. "Over the years, NREL has provided a lot of support research that we couldn't have done ourselves. NREL has also been a world leader in developing computerized wind turbine design codes. That's something that no manufacturer could ever do—and as you explore more flexible and lighter weight machines and more advanced concepts, these codes are really essential."

For more information on NREL's wind turbine design program, contact Brian Smith at (303) 384-6911. For information on research partnership opportunities, contact Darrell Dodge at (303) 384-6906. ♦

Predicting Energy Use for Buildings

A new NREL tool can help building designers and managers predict and monitor energy use

Buildings in the United States consume about 35% of our nation's total energy supply at a cost of $193 billion a year. NREL has developed a new technique for predicting and monitoring building energy performance that could help reduce these costs while making our homes and businesses more comfortable.

Called short-term energy monitoring (STEM), the new technique quickly and easily predicts long-term energy performance such as annual heating requirements. STEM is also very accurate; tests conducted in homes and small commercial buildings have shown that predicted energy use differs from actual measurements by less than 5%. This makes STEM a valid way to verify energy performance for third-party financing and utility rebate programs.

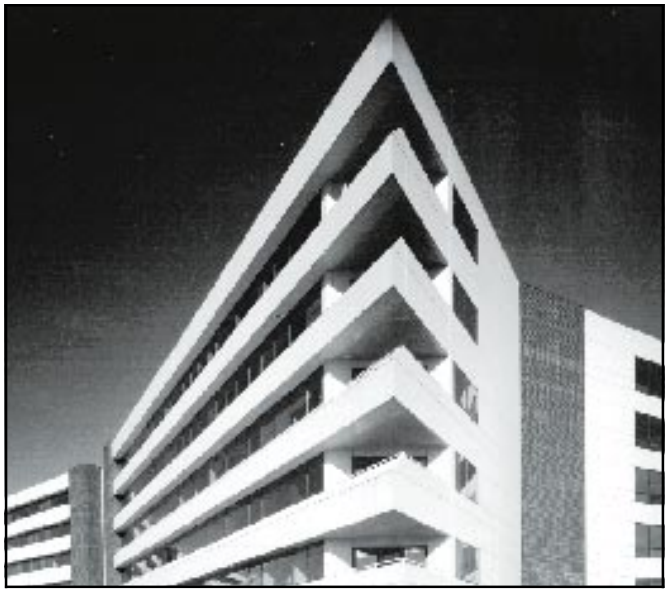
Architects and building managers will find STEM useful in isolating the individual components that affect energy use. For example, tests can be conducted before and after adding insulation, window shading, or performing a furnace tune-up to give precise information on how these changes affect a building's energy consumption.

A STEM test typically takes three days, during which a computer-controlled data acquisition system gathers hourly energy data for analysis. The system automatically turns test equipment on and off, scans data channels, and calculates hourly averages from the recorded data.

The recorded data allow STEM to calculate four key building characteristics: heating efficiency, building-load coefficient, effective building thermal mass, and effective solar gain. This information is useful in determining the efficiency and effectiveness of furnaces, heating and cooling systems, ventilation, thermal storage, and other facets of building energy use.

NREL researchers have conducted an extensive series of tests in a single house, with tests every 10 days for a five-month period. Each test supplied an independent measure of adjustment factors and estimated performance during the period. The variation in calculated adjustment factors led to an expected accuracy rate exceeding 95% in predicting long-term energy performance.

In addition, researchers have used STEM to conduct short-term tests on 40 houses from California to Virginia. The technique is also useful for analyzing the energy performance of smaller commercial buildings and modular units. For example, NREL and All American Modular Co. of Arlington, Texas, have used STEM to study the structural differences between two modular office buildings. Test results showed that one design used 40% less heating to keep the same inside temperature.



Warren Gretz, NREL/PIX132

Poorly insulated windows account for 25% of all heating and cooling requirements in the United States, at a cost of $22 billion per year. Short-term energy monitoring can help architects predict the energy savings possible with window shading and other building design elements.

NREL researchers are expanding STEM applications to include large commercial buildings, including offices with complex heating, ventilating, and air-conditioning systems.

For more information on STEM, contact Doug Balcomb at (303) 275-6028. ♦

Advancing PV Technology

Warren Gretz,NREL

NREL's Outdoor Test Facility offers capabilities ranging from solar radiometric measurements to simulated hail strikes

by Mike Coe

Since the 1980s, photovoltaic companies nationwide have sent prototype cells, modules, and systems to NREL's Outdoor Test Facility (OTF) for testing and evaluation. The result has been increased photovoltaic performance, reliability, and safety.

Now, a new 10,000-square-foot laboratory building at the OTF field site will make this collaboration even stronger by offering enhanced facility and project capabilities to the photovoltaic community. Dedicated during a grand opening ceremony on September 7, the building consolidates outdoor test activities with indoor testing and evaluation previously conducted in various buildings and trailers.

"The new OTF will allow us to conduct engineering research and complete exploratory performance testing in one location under natural, simulated, and accelerated test conditions," said Dick DeBlasio, manager of NREL's photovoltaic module and system performance and engineering projects.

Testing at the OTF helps NREL and its industry partners to evaluate advanced photovoltaic technologies. State-of-the-art laboratories, outdoor test beds, and support services are used to test and characterize over 3500 photovoltaic cells and modules each year. The results help validate advances in module and system performance as well as improve reliability and safety.

"Manufacturers and users come to us to cross-check, calibrate, and compare results because we have one-of-a-kind test and measurement systems here," DeBlasio said.

Indoor testing under controlled conditions

Indoor activities include module characterization, environmental durability testing, electrical and mechanical integrity testing, diagnostics, failure analysis, and solar radiometric measurements.

In a high bay area, large chambers are used for accelerated environmental durability testing. Modules are subjected to elevated and controlled temperature, humidity, and light stress factors to evaluate their capacity to withstand outdoor conditions such as temperature cycles, damp heat, humidity-freeze, and long-term

Above: Photovoltaic systems will be installed on the front roof of the new laboratory building to test systems under actual operating conditions.

exposure to sunlight or ultraviolet light.

Mechanical tests include flexing modules 10,000 times at different angles and firing standardized, specially-made, one-inch-diameter ice balls at modules at an impact velocity of 52 miles per hour to simulate hail strikes.

In a laboratory painted black to prevent light reflection, researchers use pulse and continuous simulators to measure photovoltaic conversion efficiency under standard test conditions. The pulse simulator uses rapid, short bursts of light, while the continuous simulator uses a steady light source. Both simulators are needed to fully characterize modules.

In another lab, modules are submerged in water, then subjected to elevated voltages ranging from 2000 to 3000 volts to measure current leakage. Tests evaluate electrical insulation and verify that moisture will not enter active portions of a module, which could cause corrosion, ground faults, or electrical safety hazards.

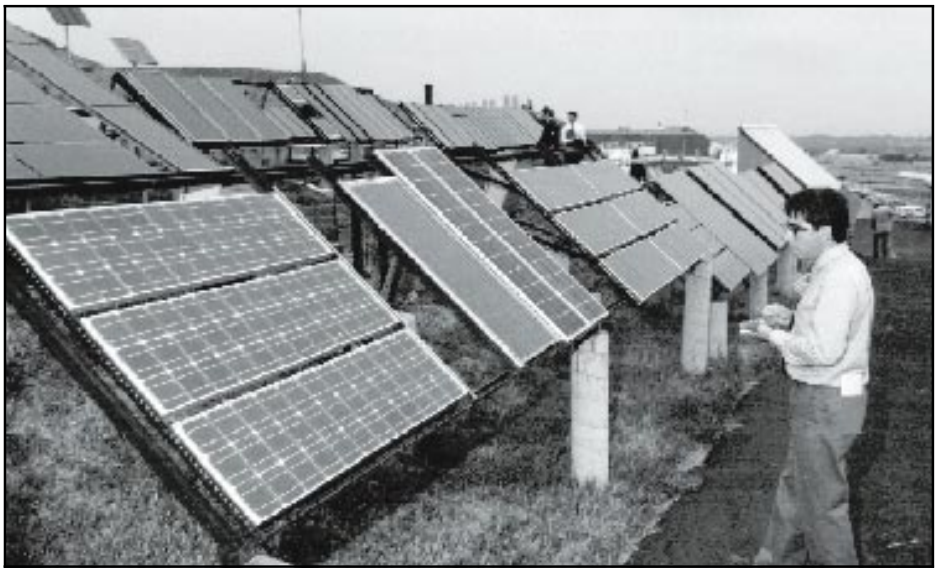
Other laboratories are used for nondestructive and destructive testing; accelerated testing to reproduce failure modes and mechanisms; preparing modules and cells for testing and outdoor deployment; and for developing, characterizing, and evaluating solar simulators and related equipment.

Outdoor testing under real conditions

At the OTF field site, more than 100 modules and six systems are being tested and evaluated for performance, reliability, and energy production under prevailing outdoor conditions.

NREL is also monitoring two six-kilowatt systems mounted atop the nearby Solar Energy Research Facility (SERF), and a 15-kilowatt system in New York. Real-time data on performance of these modules and systems is sent to the OTF's outdoor test and measurement laboratory for analysis.

The two systems at SERF, five of the six systems at the OTF, and the New York system are connected to the local utility grid, providing NREL with valuable real-world experience under actual utility conditions.



Warren Gretz, NREL

More than 100 modules and six systems are now being tested under actual operating conditions.

State-of-the-art laboratories, outdoor test beds, and support services are used to test and characterize over 3500 photovoltaic cells and modules each year.

Setting standards

NREL researchers also work with industry to set uniform and consensus standards and codes. This work provides guidelines for test methods and design techniques by establishing specific steps or criteria to follow when testing or designing modules or systems. These consensus standards (IEEE, ASTM, IEC) represent good engineering and testing practices. They are coordinated through an NREL-sponsored annual standards and code forum.

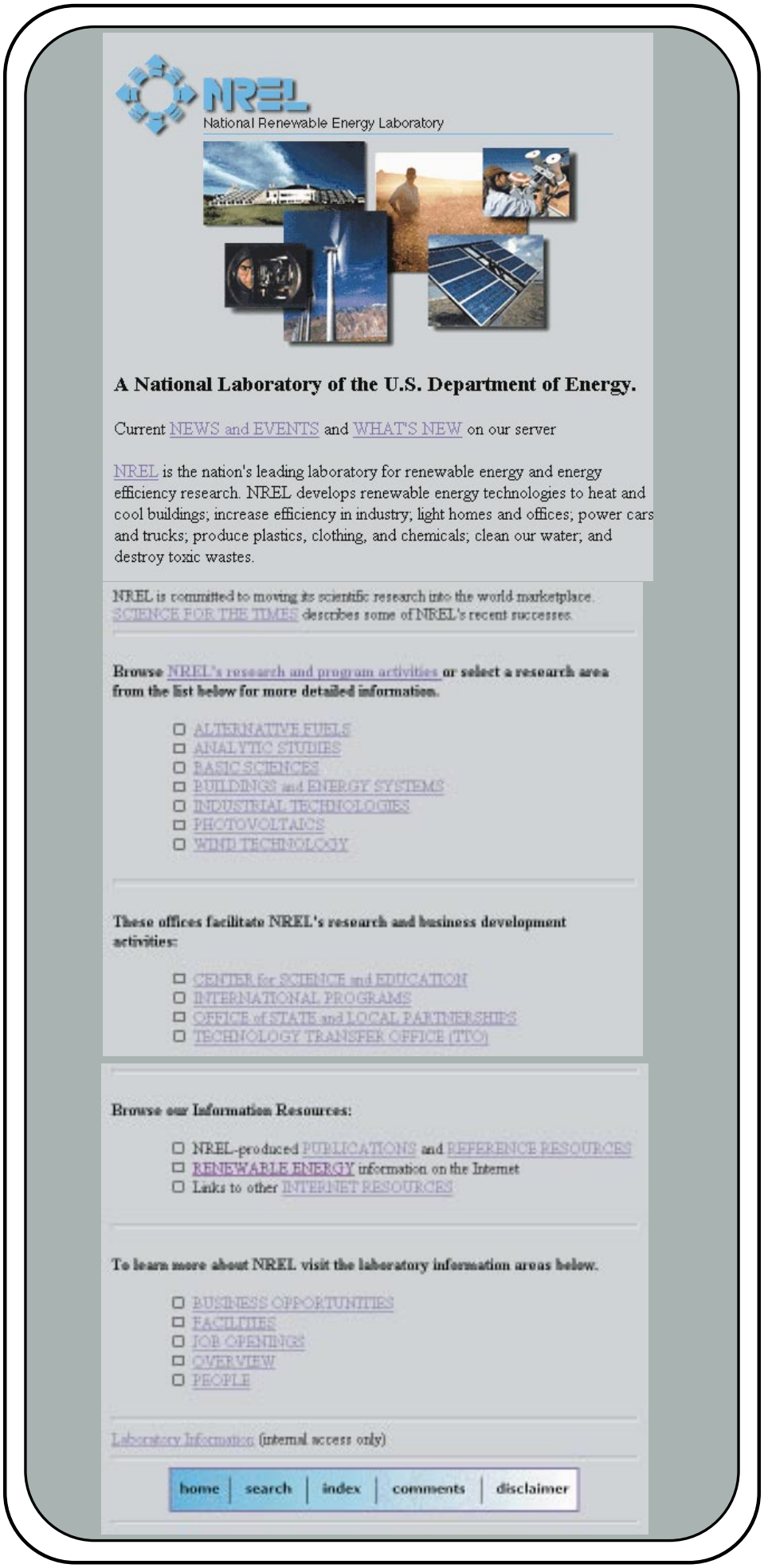
Improving test methods

The OTF is helping NREL and the photovoltaic industry to advance photovoltaic technologies. But as technologies continue to improve, so must test and evaluation methods.

"The test methods needed to evaluate new photovoltaic technologies must be developed in collaboration with industry and validated to ensure the technologies perform reliably and safely," DeBlasio said.

The OTF helps make this possible.

For more information on industry partnerships and NREL's capabilities, contact Dick DeBlasio at (303) 384-6760. ♦



NREL

by Patrick Summers

At NREL, we're taking a giant step forward to become *the* source of renewable energy information on the Internet.

NREL's newly redesigned "Home Page" gives the Laboratory's on-line presence a sharper focus on research and technology applications. Information on basic research, international energy developments, and business issues— as well as state and local initiatives— are literally at your fingertips.

Here's a closer look at several key areas of information available on NREL's Internet Home Page.

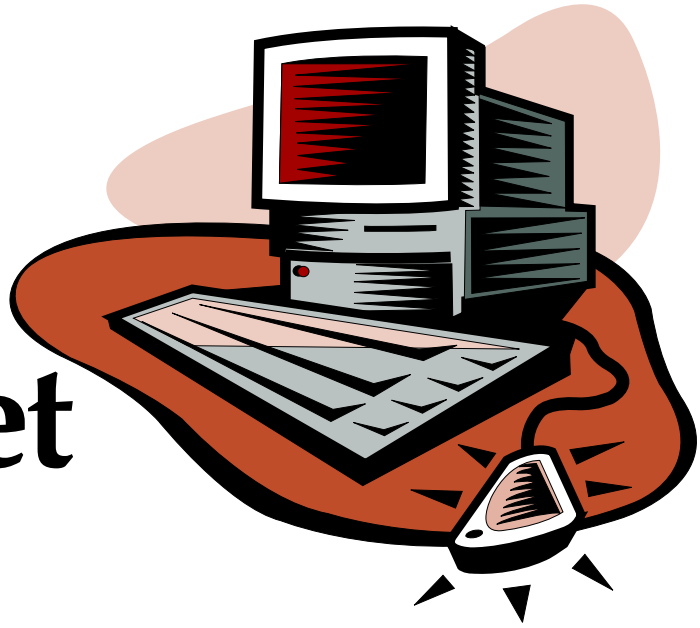
News and current events

This is where you will find NREL's news releases, a calendar of conferences and special events, and information on how to get special products such as videotapes on renewable energy and energy efficiency technologies.

What' new

You can locate information in any of NREL's on-line subject areas according to a key word or phrase. Just use the query interface listed under "What's New." Also found here is a breakdown of NREL publications by subject. This is a listing of NREL-produced publications in a wide range of research areas available to the public.

on the Internet



The hybrid vehicle program's Home Page offers graphics, simulations, and performance data in a way designed to help you learn about how hybrid vehicles work.

Research and program activities

This is a detailed look at NREL's research divisions and provides a wealth of technical and program information.

For example, under the Alternative Fuels Division is the Biofuels Information Center, which offers a biofuels update newsletter and a national biofuels data base.

Research and business development

Two main components of this section are International Programs and the Technology and Business Ventures Office. Through colorful graphics you can click on any continent and get information on doing business in more than a dozen countries under International Programs. The Technology and Business Ventures Office will show you how to do business with NREL. It covers cooperative research and development agreements, licensing agreements, and how to use NREL facilities.

Reference resources

This section is a bonanza of useful data bases and information. The Alternative Fuels Data Center is here, along with resource maps for solar radiation and wind energy. The NREL photograph file offers a variety of images related to renewable energy research and development.

Renewable energy information on the Internet

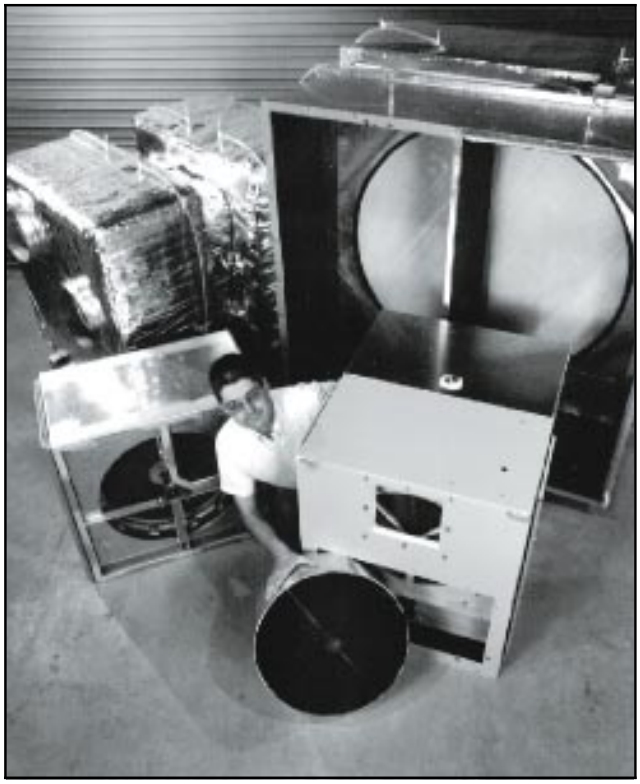
NREL is part of a larger DOE network of energy-related Internet sites. One of these is EREN, which can point you in the right direction with almost any energy-related question. ♦

Home Page

The best way to discover what's available from NREL on the Internet is to be a browser: visit the web site and have a look. NREL's Home Page is continually being developed and updated. To access NREL's Home Page, use the Internet address http: //www.nrel.gov.

Opening Doors for Desiccant Cooling

Hotels, restaurants, and office buildings may soon enjoy healthier, more comfortable indoor air thanks to joint research supported by NREL



Warren Gretz, NREL

NREL researcher Doug Powell displays desiccant dehumidifier wheels in various stages of testing and development.

by Linda R. Brown

Businesses in the United States could save $750 million and offset the use of 500,000 barrels of imported oil every year by capitalizing on advances in desiccant cooling technology.

Desiccant systems use materials such as silica gel to remove moisture from the air while cooling it. Solid desiccant materials are often embedded in a rotating wheel, where they can be dried and regenerated for continued use by exposing them to heat. Because desiccants remove water from the air without condensing it, they control humidity more effectively than air conditioners. They also operate without the use of chlorofluorocarbons (CFCs) and can handle the larger flow rates of outside air required by new indoor air quality standards.

For the past decade, this technology has proven its worth in warehouses, supermarkets, ice skating rinks, and other places where controlling humidity and temperature are important. But high costs have prevented desiccant systems from coming into widespread use in other applications such as hotels, restaurants, and office buildings. And that's where the total energy savings could add up to as much as 0.3 quadrillion Btu's per year.

With funding from DOE's Office of Building Technologies, NREL is working with the Gas Research Institute and several U.S. manufacturers to make this happen. Activities include testing advanced desiccant materials, developing computerized design codes for desiccant systems, and evaluating the performance of desiccant wheels using NREL's sophisticated facilities.

The most significant near-term breakthrough may come with the use of natural gas—instead of electricity—as an inexpensive energy source for drying and regenerating desiccant materials. As more desiccant cooling systems come into use and prices decline, markets are expected to open up for solar-driven technology.

Expanding markets with gas

The potential for gas-fired desiccant cooling is illustrated by a recent study of a 346,000-square-foot office building in Houston, TX. New standards for indoor air quality require an outside-air ventilation rate that's three to four times the current practice. But the building's heating, ventilation, and air-conditioning (HVAC) system was unable to handle such a large increase in air volume and moisture.

Two options were considered: adding a vapor-compression chiller with a 500-ton capacity, or adding a gas-fired desiccant system to the existing 850-ton chiller. Analysis showed that the gas-fired desiccant option would save $27,100 annually in energy costs when compared with the conventional approach.

Even more savings could be realized by improving the performance of desiccant cooling systems driven by natural gas. With support from DOE's Gas Cooling Program, NREL is helping several U.S. companies evaluate a variety of desiccant materials, components, and system configurations.

Industry partners include Englehard/ICC Technologies of Philadelphia, PA, which is developing dehumidifiers based on titanium silicate desiccant. This material may be able to be adsorb (remove) more moisture than other desiccants and to regenerate at lower temperatures for greater energy savings. NREL is also testing silica gel and lithium chloride wheels for Munters/Cargocaire of Massachusetts, which

uses the material in desiccant systems for supermarket applications.

These and other cost-shared partnerships with companies such as U.S. Rotors and Air Technology Systems, both of Maryland, primarily involve material and component testing. In 1996, NREL plans to test wheels from LaRoche Industries of Baton Rouge, LA, and SEMCO Manufacturing of Columbia, MO. With further funding, tests can proceed to the systems integration stage.

Benefits abound

In addition to assisting individual companies as they bring improved products into the marketplace, NREL's desiccant cooling research will generate many benefits for the industry in general.

For example, testing will result in an extensive data base of desiccant cooling options that can help architects, building managers, and consumers make objective, informed decisions about which technology is appropriate for a specific application. In addition, the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) will use NREL-generated data to evaluate its proposed commercial standard for dehumidifiers.

A walk through NREL's desiccant cooling test facilities

With funding from DOE's Office of Energy Efficiency and Renewable Energy, NREL has developed a complementary set of experimental facilities to evaluate new and promising desiccant materials, measure the performance of prototype systems, and validate mathematical models for future design efforts. The output from each evaluation facility serves as input for the next one. If initial tests show promise, both the observed results and the validated models can be used to gather information for newer or larger test specimens.

The characteristics that cause water to adsorb (cling) to a desiccant material are measured with a quartz crystal microbalance or other equipment as determined by the form and shape of the sample. Promising desiccant materials are bonded or embedded in a dehumidifier matrix material so that adsorption properties can be confirmed at this stage of component production.

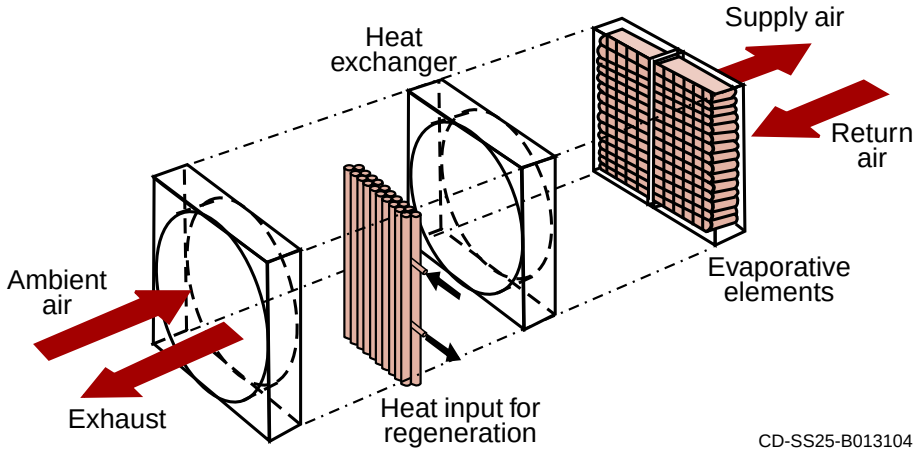
Performance characteristics of desiccant matrices are measured in the desiccant heat- and mass-transfer test facility. If the dehumidifier matrix still shows promise, NREL researchers can build a prototype rotating dehumidifier wheel for analysis in the HVAC test facility. The resulting data can be used to evaluate the wheel's performance under real operating conditions. Other HVAC components can also be tested, including evaporative coolers, heat exchangers, heat pipes, and cooling coils.

Another NREL facility examines the effects of contamination by degrading desiccant samples in a controlled manner. The eventual goal is to evaluate strategies to prevent or mitigate degradation. The result should be more compact, cost-competitive desiccant cooling systems with service lifetimes of 15 years or more.

Future studies of desiccant cooling systems will help improve indoor air quality in buildings throughout the nation. Accurate, modular, easy-to-use system models can be integrated into HVAC and building simulation programs. Research should allow the development of handbooks, charts, and user-friendly software for use by anyone interested in alternatives to conventional air conditioning.

So far, NREL's cooperative research has focused on solid desiccants such as silica gel and polymers. But upcoming efforts will involve qualified industry partners in the development of advanced liquid desiccants.

For more information on desiccant cooling technology, contact NREL's Steve Slayzak at (303) 384-7527. ♦



Solid desiccants such as silica gel or Type 1M material are embedded on a rotating wheel. When mounted in the cooling system, the material removes moisture from air passing through it. The wheel is dried and regenerated using a heating source such as natural gas.

New Tool for PV Diagnostics

A non-destructive technique measures shunt resistance of individual cells in PV modules to quickly identify electric performance problems

by Howard Brown

It's simple, it's free, and it quickly gives you accurate quantitative data for one of the more important characteristics of individual cells in a photovoltaic (PV) module. Too often overlooked, shunt resistance is one of the most basic and informative parameters of PV performance.

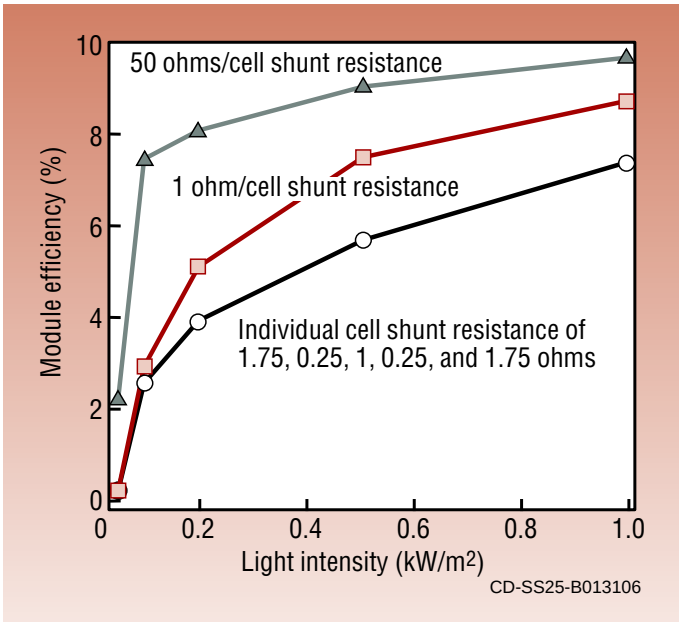
Low shunt resistance of individual cells should be one of the first signs to look for in identifying electrical performance problems with PV modules. Until now, however, once a module was encapsulated, it was no longer practical to measure those resistances.

NREL researchers recently developed a method that allows easy and accurate measurement of the shunt resistance of each cell in a series-connected, encapsulated module—without damaging the module. The technique is quick and simple, requiring only standard, inexpensive electronic equipment.

Powerful diagnostic

Electrical shunts are low-resistance leakage paths that divert current away from the intended power load in PV systems. For PV modules with otherwise effective materials and design, shunt losses are a primary symptom of problems that can cause cell failure or poor performance.

Cells with very low shunt resistance are effectively dead. Cells with marginal shunt resistance may function adequately at high light levels, but not at low levels. A greater proportion of cell output is lost under reduced light, so that their efficiency decreases dramatically. Also, cells with localized shunts—as possibly indicated by marginal shunt resistance—may be more likely to short out and fail when subjected to the stresses of environmental exposure and when connected together as a generating system.



This graph shows calculated maximum power conversion efficiencies for a "good" module (50 ohms/cell shunt resistance) and for "marginal" ones with lower shunt resistance.

NREL's shunt-resistance measurement technique is particularly valuable for assessing thin-film modules without damaging them.

Shunt resistance is a particularly powerful diagnostic parameter. It applies to any normal light condition, not just the one under which it was measured. Because shunt resistance is quantitative, you can set threshold values for quality control and compare values from different cells or modules. You can also check the values again after stress testing or regular use or if the module later fails. Shunt-resistance values can also be used in computer models to predict the performance of modules under the varying light intensities found at particular locations.

Measuring shunt resistance can help you detect problems with individual cells that are not readily detectable by traditional full-module current-voltage (I–V) tests. The NREL technique is most accurate

Tom McMahon, NREL

NREL's technique for measuring the shunt resistance of individual cells in a photovoltaic module needs only inexpensive, readily available equipment.

for the low shunt-resistance values that indicate problem cells.

The per-cell-average slope of a module's current-voltage curve at short-circuit current is a good indicator of the shunt resistance needed for effective performance. Resistance less than that slope indicates a serious shunt; less than several times that slope will be only marginal.

Simple and nondestructive

Taking less than a minute per cell to measure, the NREL technique gives cell-by-cell shunt resistance for modules with any number of series-connected cells. It does so without removing protective cover material to get at individual cells or otherwise damaging the module.

As far as we know, this is the only nondestructive test for measuring shunt resistance of individual cells. The technique requires an AC signal generator, a DC voltage supply, an operational amplifier, and a phase-sensitive amplifier—all common laboratory equipment.

This remarkably simple technique is based on sequentially blocking the light to each cell in a module, measuring the open-circuit resistance, and subtracting the open-circuit resistance of the fully exposed module. If that difference is small, the cell has low shunt resistance that will significantly impair module performance.

Many valuable applications

Testing the shunt resistance of individual cells is valuable for all phases of the product life cycle of PV modules. Measuring shunt resistance can verify the adequacy and optimization of cell fabrication steps. It can be used for module performance characterization and qualification testing. During manufacture, it can be an excellent quality-control and quality-assurance tool. And it is very helpful for failure analysis.

Fabrication verification can be determined by shunt-resistance testing. Because measurements are quantitative and can be easily taken at any step in the production process, it is possible to pinpoint at which step problems are introduced. For example, visual defects do not necessarily cause performance problems. Shunt-resistance measurement would tell whether visual defects are of concern and would also identify problems that may have no visible manifestation.

Module performance testing assesses module output during exposure to see how performance will change with time and use. Shunt resistance of individual cells can be quickly measured at the beginning of the test period and again at desired intervals. It will often show problems that other module diagnostic tools do not. Modeling that includes shunt-resistance values can predict performance for the actual sunlight levels at a particular location.

Qualification testing screens modules for reliability and durability. Shunt-resistance testing can provide an electrical baseline, including

immediate identification of problem cells, and can then be repeated at any stage of the full qualification test procedure.

Quality assurance/quality control could benefit greatly from NREL's shunt-resistance measurement technique. The technique can be automated for a particular module design, providing rapid quantitative assessment at any desired step in the production process. Minimum acceptable shunt-resistance limits can be set, and patterns of low resistance can point out problems with the production process. For example, for thin-film modules, low-resistance cells occurring at the same spot in the module may indicate a scribing problem or a problem with the manufacturing system.

Failure analysis determines what went wrong with modules that have failed. Shunt resistance is an exact value that enables direct quantitative comparison of cells to other problem and nonproblem cells. Shunt-resistance testing identifies the individual cells that have electrical problems. Researchers can then examine those cells using microscopic or chemical analysis or other diagnostic tools to look for possible root causes.

Thus, in all phases of the PV-module product life cycle, NREL's shunt-resistance measurement technique quickly locates individual cells that are poor contributors to the electrical performance of the module, providing a focus for further investigation and corrective action.

For more information on NREL's shunt resistance measurement technique, contact Tom McMahon at (303) 384-6762. ♦

Just follow these steps

(1) Set up a circuit consisting of a low-frequency (2 to 10 Hz) AC voltage source (signal generator), a DC voltage source, and an operational amplifier connected to a phase-sensitive, lock-in amplifier.

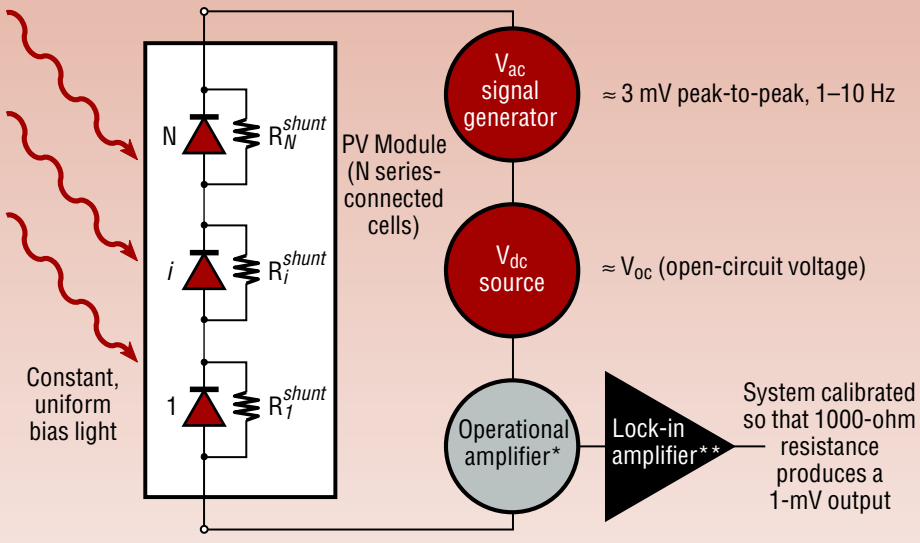
(2) Connect the circuit to a 1000-ohm resistor and set the AC voltage (which will be 2 to 5 millivolts) to get a reading of 1 millivolt on the lock-in amplifier.

(3) Replace the resistor with the module to be tested. Set the DC voltage source to match the open-circuit voltage of the module for the light conditions under which it will be tested (sunlight through a window—about 30 mW/cm^2—is fully adequate).

(4) With the module exposed to constant, uniform light, simultaneously apply both the DC and AC voltages to the terminals of the module and record the lock-in amplifier reading. This voltage reading is the inverse of the resistance; divide 1000 by this value to get the shunt resistance of the entire module (R_A in the equations).

(5) Sequentially darken each cell of the module by covering it with opaque tape or an appropriately shaped rubber mat and record the reading for each cell (R_B in the equations).

(6) The difference in resistance between the reading for each cell as it is covered and the reading with no cells covered is the shunt resistance for the covered cell (R_C in the equations).



Step 4: $R_A = \sum_{1}^{n} R_i^{light}$

Step 5: $R_B = \sum_{1}^{n-ith} R_i^{light} + R_i^{dark}$

Step 6: $R_C \equiv R_B - R_A = R_i^{dark} - R_i^{light}$

If $R_B >> R_A$, then $R_C = R_i^{dark} - R_i^{light} \approx R_i^{shunt}$

If $R_B \approx R_A$, then cell *i* is shunted; by experience, $R_C \approx R_i^{shunt}$

CD-SS25-B013107

Landfill Projects That Pay

Local governments find ways to turn a public nuisance into the sweet smell of success

by Mike Marsh

How often can a local government make money by complying with health and environmental regulations? That's what some cities and counties are doing as they employ new technology to turn landfill gas into salable electricity, heat, and steam.

Pending regulations from the U.S. Environmental Protection Agency will require as many as 700 landfills to control emissions from decomposing garbage. Volatile organic compounds in landfill gas interact with nitrous oxides in the air to form ozone, a primary constituent of urban smog. In addition, the buildup of methane—the main energy component of landfill gas—sometimes can be dangerous. More than 40 landfill fires and explosions resulting in 10 human fatalities have been recorded in the United States.

Above: Gas produced from decomposing garbage in landfills is a potential liability soon to come under regulation by the U.S. Environmental Protection Agency. Converting the gas to energy can produce revenue while eliminating liability. (Photo courtesy of David Hunter)

But methane and other landfill gases can be safely collected and used to generate revenues rather than complaints, as these state and local organizations have discovered.

Rhode Island earns royalties

As environmental manager of Rhode Island's Central Landfill, Dennis aRusso doesn't have to worry about odors from decomposing garbage. That's because the gas from his company's landfill is captured and converted to electricity. The enterprise rakes in almost $600,000 in royalties per year for Rhode Island Solid Waste Management Corp., a state-chartered organization responsible for managing the landfill.

"There's no reason to have a landfill and not recover the gas," aRusso said. "It's a huge advantage—it's positive all the way around."

The 154-acre Central Landfill receives about 90% of the state's garbage. In the early 1980s, residents from the nearby town of Johnston began complaining about odors from the site. Rhode Island Solid Waste Management hired a private company to study gas flow and assess the feasibility of using gas to generate electricity for profit. The results of the study were positive. In 1989, the Northeast Landfill Power Joint Venture completed construction of a new gas-to-electricity plant.

Today the facility uses landfill gas to supply as much as 12.3 megawatts of electricity, enough to serve the needs of about 17,000 homes. Electricity is sold to a local subsidiary of New England Power. Rhode Island Solid Waste Management receives about $50,000 per month in royalties for the rights to use the gas.

Lane County stabilizes utility rates

Lane County, OR, also began exploring the possibility of a gas-to-electricity plant in the 1980s. The resulting facility at the Short Mountain Landfill is a win-win situation for all concerned.

"The win for us is that we don't have to develop a gas control project," says Mike Turner, manager of Lane County's solid waste division. "The primary benefit for the entire community is that a resource is not being lost."

Annual gross revenues from selling steam range from $450,000 to $500,000. Of this amount, the city of Raleigh receives annual royalties of about $70,000.

Revenues from the 1.6-megawatt power plant help stabilize local utility rates. And because the local utility district is consumer-owned, economic benefits are passed directly to its customers.

"With all the rising landfill gas regulations, the county would have to learn a whole new business if we

weren't here," says Alan Zelenka, a power resource specialist. "It's a lot nicer to have someone else do all this."

Raleigh generates steam

Landfill gas has a medium-Btu rating. With minimal cleaning, it can be used in conventional boilers to create steam for industrial processes. This is often the most cost-effective use of landfill gas because it doesn't require expensive equipment such as generators.

For example, the city of Raleigh, NC, uses a boiler fueled by landfill gas to generate steam at an average rate of 24,000 pounds per hour for a local pharmaceutical company. Gas is collected from the city-owned Wilder's Grove Landfill. Two private developers—Natural Power Inc. and Raleigh Landfill Gas Corp.—invested a total of $1.6 million in the project. Annual gross revenues from selling steam range from $450,000 to $500,000. Of this amount, the city of Raleigh receives annual royalties of about $70,000.

"We've created an asset out of a potential liability," says Marshall Ashcraft, a budget and management analyst with the city manager's office. "This is an excellent example of public-private partnership."

Tapping into the potential

Currently about 100 fully commercial projects in the United States provide electricity and steam for oil refineries, food-processing plants, brickworks, hotels, hospitals, junior colleges, and greenhouses. Yet this is a mere fraction of the potential for using landfill-gas-to-energy technologies. Research now being conducted by DOE and its industry partners is aimed at overcoming the barriers to more widespread commercialization.

This article was adapted from Using Landfill Gas for Energy: Projects that Pay, *a fact sheet in a series intended for city and county governments. NREL has produced about 30 of these four- to six-page fact sheets explaining how local governments can integrate renewable energy and energy efficiency into their operations. Dollar and energy savings are quantified in a case-study format. For more information, contact Bruce Green at (303) 275-3621.* ♦

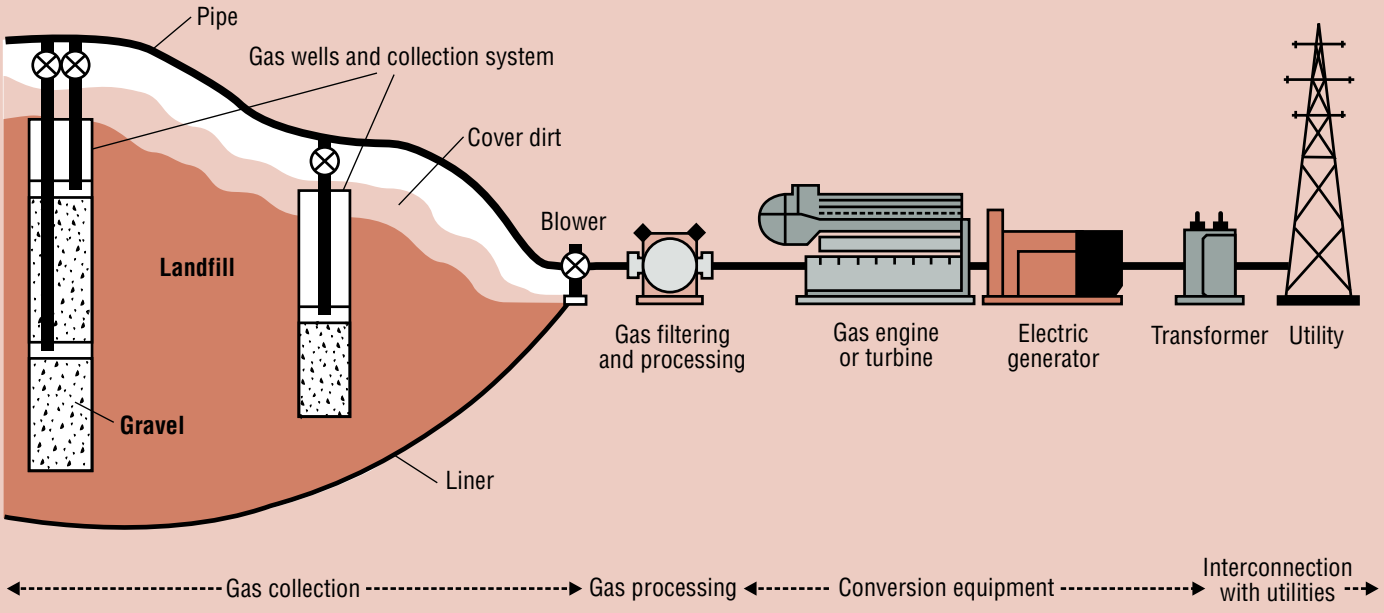
How landfill gas to electricity works

The most common use of landfill gas is to generate on-site electricity. There is little difference between an electric generating plant using landfill gas and one using natural gas or diesel fuel.

Typically, gas is collected by a network of vertical wells and horizontal shafts strategically located throughout the landfill. Perforated plastic pipes are inserted into the wells and connected by larger header pipes that route the gas to a central processing station. A partial vacuum created by blowers or fans keeps the gas flowing through the system.

After delivery to the central processing station, the gas is filtered to remove particles, condensates, and trace elements. Internal combustion engines or gas turbines then convert the filtered gas into salable electricity.

Typical Landfill Gas-to-Electricity Facility



Source: Rhode Island Solid Waste Management Corporation

CD-SS25-B013101

Biofuels for Transportation

NREL/SP-420-5439, DE93000091

America's vehicles gobble up about two-thirds of all the oil we consume annually, which is alarming because we now import more than half our oil. Biofuels—fuels produced from agricultural and forestry residues, organic wastes, and energy crops—will help keep America's wheels rolling, conserve resources, clean up the air, and reduce oil imports. This information packet explains what biofuels are and describes how NREL is working with industry through DOE's National Biofuels Program to help produce affordable new transportation fuels.

Biomass Power: Program Overview for FY 1993-1994

DOE/GO-10095-089, DE94000241

Did you know that plants and organic wastes can be used to produce electricity as well as transportation fuels? Members of the emerging U.S. biomass power industry—which employs nearly 70,000 people in more than 1000 power plants across the nation—are working with DOE researchers in the national laboratories to develop or refine the three main biomass power technologies: direct combustion, gasification, and pyrolysis. This educational 12-page booklet describes recent major achievements and goals for future research and development.

Transmission and Distribution Technologies

DOE/GO-10095-013, DE95000205

The backbone of the nation's electricity network is the profusion of wires, transformers, switches, meters, poles, insulators, and other devices that make up our transmission and distribution (T&D) system, which must support both the growing demand for electricity and a rapidly changing utility environment. Increased competition, new power generation methods (such as renewables), and the need for enhanced services are prompting the kinds of innovations described in this informative 20-page overview of the work of DOE's T&D Technologies Program.

Benefits & Breakthroughs Newsletter

DOE/GO10095-183

Would your company like to improve profits, productivity, and competitiveness? Use energy more efficiently? Reduce emissions and pollutants? Or conduct collaborative research and development on new industrial technologies? If so, you'll want a copy of this new, informative newsletter from DOE's Office of Industrial Technologies. It describes current opportunities for collaborative R&D projects and partnership programs that are already saving energy and dollars in some of the nation's most profitable companies.

These publications are available without charge from NREL's Document Distribution Service, 1617 Cole Blvd., Golden, CO 80401-3393, (303) 275-4363, FAX (303) 275-4053.

NREL-Hosted Meetings

World Renewable Energy Congress (WREC)
June 15 through June 21; Denver, Colorado
Jessica White, (303) 275-4358, FAX (303) 275-4320

National/International Meetings

Building Energy—First International Solar Electric Building Conference, 12th Annual Quality Building Conference, and RENEW '96
March 4 through March 6; Boston, Massachusetts
Northeast Sustainable Energy Association, (413) 774-6051, FAX (413) 774-6053

Thirteenth International Seminar on Primary and Secondary Battery Technology and Application
March 4 through March 7; Deerfield Beach, Florida
Florida Educational Seminars, Inc., (407) 338-8727, FAX (407) 338-6887

7th Annual U.S. Hydrogen Meeting and Exhibition
April 2 through April 4; Alexandria, Virginia
Angela Barbara, National Hydrogen Association, (202) 223-5547, FAX (202) 223-5537

Solar 96 National Solar Energy Conference—Sundancin' in the Smokies
April 13 through April 18; Asheville, North Carolina
American Solar Energy Society, (303) 443-3130, FAX (303) 443-3212

8th Annual American Tour de Sol
May 10 through May 17; New York to Washington, D.C.
Northeast Sustainable Energy Association, (413) 774-6051, FAX (413) 774-6053

WINDPOWER '96: 26th Annual Conference and Exhibition of the American Wind Energy Association
June 23 through June 27; Denver, Colorado
L. Redmond, American Wind Energy Association, (202) 383-2511, FAX (202) 383-2505

Technical Reports

The following technical reports provide technical information on some of NREL's research and analysis projects. These reports are available in limited quantities from NREL's Document Distribution Service at (303) 275-4363 or FAX: (303) 275-4053.

Advanced Hydrogen/Methanol Utilization Technology Demonstration. Phase II: Hydrogen Cold Start of a Methanol Vehicle. (May 1995). Work performed by Hydrogen Consultants Inc., Littleton, Colorado. Order no. TP-425-7529; 45 pp.

Crandall, R.; Luft, W. (June 1995). *Future of Amorphous Silicon Photovoltaic* Technology. Order no. TP-411-8019; 26 pp.

Diebold, J.P.; Scahill, J.W.; Czernik, S.; Phillips, S.D.; Feik, C.J. (May 1995). *Progress in the Production of Hot-Gas Filtered Biocrude Oil at NREL*. Order no. TP-431-7971; 15 pp.

Green, H.J.; Manwell, J. (April 1995). *HYBRID2–A Versatile Model of the Performance of Hybrid Power Systems*. Order no. TP-441-7807; 12 pp.

Kiss, G.; Kinkead, J.; Raman, M. (March 1995). *Building-Integrated Photovoltaics: A Case Study*. Work performed by Kiss Cathcart Anders Architects, P.C., New York. Order no. TP-472-7574; 136 pp.

Osterwald, C.R., Hammond, R.L.; Wood, B.D.; Backus, C.E.; Sears, R.L.; Zerlaut, G.A.; D'Aiello, R.V. (April 1995). *Photovoltaic Module Certification/Laboratory Accreditation Criteria Development*. Order no. TP-412-7680; 181 pp.

Potter, T.F.; Lyons, C.E. (March 1995). *Next Generation of Automobile Emissions* Reduction: Innovative Control of Off-Cycle *Emissions*. Order no. TP-473-7570; 20 pp.

Seventeenth Symposium on Biotechnology for Fuels and Chemicals: Program and Abstracts of the Symposium, 7–11 May 1995, Vail, Colorado. (1995). Order no. SP-420-7849; 200 pp.

Shipley, D.E.; Miller, M.S.; Robinson, M.C.; Luttges, M.W.; Simms, D.A. (May 1995). *Techniques for the Determination of Local Dynamic Pressure and Angle of Attack on a Horizontal-Axis Wind Turbine*. Work performed by University of Colorado, Boulder, Colorado. Order no. TP-442-7393; 56 pp.

Zweibel, K. (April 1995). *Thin Films: Past, Present, Future*. Order no. TP-413-7486; 18 pp.

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DOE's Office of Energy Efficiency and Renewable Energy is managed by Christine Ervin, Assistant Secretary

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