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SPAIN

WINDPOWER

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WIND POWER IN SPAIN

SPAIN'S WIND-POWER SECTOR HAS CONTINUED ITS DRAMATIC GROWTH. INSTALLED CAPACITY IN THE COUNTRY DOUBLED IN ONLY THREE YEARS, FROM 2003 TO 2006, AND IS EXPECTED TO DOUBLE AGAIN BY 2010. SPANISH COMPANIES RANK IN THE WORLD'S TOP 10 AMONG BOTH WIND-FARM OPERATORS AND TURBINE MANUFACTURERS.

In recent years, wind power has entered the mainstream. Prices have dropped nearly to those of conventional power sources, and governments around the world are increasingly interested in renewable energy that utilizes local resources and reduces greenhouse-gas emissions. In 2007, according to the Global Wind Energy Council, more than 20,000 megawatts of capacity were installed internationally, with the United States, Spain, and China leading the way.

In Spain, where wind turbines curve over hillsides and along highways in certain areas, 2007 was a record year, with 3,523 megawatts installed—compared with an annual average of 1,200.

“It was a surprise, even for us in the wind sector,” says Alberto Ceña, director of the Spanish Wind Energy Association (AEE). “We didn’t expect to have this large a growth—but we are of course very happy.”

The rapid expansion owed a great deal to a series of government decrees, which provided the necessary stability to encourage

investment. Spanish utilities are required to purchase any wind power produced, and wind-farm operators can choose to receive a set price or sell their power on the market and receive an added premium. Spain ranks third in the world for overall installed power, only behind Germany and the United States.

In fact, wind supplied 10 percent of all Spanish electricity in 2007. On one record day, March 4, 2008, wind gusts sweeping the country provided 28 percent of the country’s total electricity.

The Spanish government also developed strict electricity requirements, or grid codes. Because wind is an intermittent resource, providing power only when it blows, the grid has to be able to cope with fluctuations and dips in electricity. When wind accounted for only a small percentage of the country’s power, such dips made little difference. But as this resource achieved greater prominence, split-second losses of power could have caused problems, especially since Spain doesn’t have strong grid connections with neighboring countries.

The company Energy to Quality, created in 2005 in part by university professors in Madrid, developed a voltage-dip generator to mimic power fluctuations in a controlled fashion. The company consults with manufacturers to analyze how short circuits affect their turbines, allowing the designs to be improved.

The government specifications and company innovations make the grid interconnections in Spain among the best in the world, according to Ceña. But though wind continues to capture a greater share of electricity production, he believes there's still room for improvement. "The main challenges for the future are from the electrical point of view," he says. "We need to integrate a great deal of wind power into the system. There are many challenges, and there are many Spanish companies working to find solutions."

Indeed, 500 Spanish companies now work in the wind-power sector, most providing services and equipment not only in Spain but around the world.

OPERATING THE SYSTEM

The Spanish power utility Iberdrola, which has been selling kilowatt-hours for more than a century, is the largest wind-power operator in the world, managing more than 7,700 megawatts of power in 19 countries.

"From a management point of view it's easy to have five or six wind farms, but when you have 7,700 megawatts blowing in the wind around the world, you have to also be innovative in the way you manage the assets," says Carlos Gascó, one of the directors of Iberdrola Renewables. "You have to make a huge effort in information flow on a real-time schedule."

That effort is carried out at the operations center, known as CORE. Rows of computers hum quietly in a spacious office in Toledo, south of Madrid. Huge screens along the front wall flash a variety of detailed images. Some display an international map of Iberdrola wind farms, shaded to indicate which are in operation. Others display a group of turbines at one particular facility; with the click of a mouse, an engineer can narrow in on the current, real-time operations of each turbine in every wind farm around the world.

Information flows in continuously, through fiber-optic channels and by satellite. More than a million points of data—more than 300 for each turbine—are transmitted from local and international facilities.

From this center, the company can initiate or halt machine operations as necessary. If engineers detect a problem in a turbine, they can alert local maintenance staff to investigate the problem and bring the turbine up to speed again quickly. "We want to reduce the time that any turbine is offline and allow each wind farm to produce more," says Gustavo Moreno, CORE manager.

"WE'RE TRYING TO OPTIMIZE THE MANAGEMENT SYSTEM AND THE DESIGN SO THAT THE ENERGY WE PRODUCE IS THE MOST EFFICIENT POSSIBLE."

This impressive facility was born of Spanish government regulations, which require all renewable-power operators to institute real-time control centers that send information to the Spanish grid operator, Red Eléctrica ("red" means grid in Spanish). The center also incorporates the company's forecasting system, which predicts the amount of wind that will be available from any given farm over the next two days.

Iberdrola has always pursued a mix of energy with a focus on clean, renewable sources, according to Gascó. Originally that meant hydropower, but in 2001 the company made a decision to invest significantly in today's cleaner technologies, including wind.

The company scaled up rapidly, from four wind farms in 2003 to more than 600 today—an expansion that demanded a rigorous approach to management. "Wind-farm operators in the past had a kind of romantic approach to energy," says Gascó. "The pioneers were engineers and technicians planting little wind farms or individual wind turbines. It has moved to being a mainstream source of power."

As Iberdrola expanded into markets around the world, Gascó says, the company also worked to navigate each country's regulations, requirements, and cultural standards. "You don't talk to someone from Argentina the same as you talk to someone in Mongolia, the U.K., or the U.S.," he says.

Today, Gascó adds, Iberdrola sees wind as an important part of the energy mix. "We saw that the political impulse is today going toward something that is more sustainable—and it's the right business decision," he says. "It's also good business for a large base of shareholders. So we think that the company is very well positioned from every point of view: technically, technologically, financially, and environmentally."

Endesa, another electric company and major wind-farm operator in Spain, built some of the earliest wind farms in the Canary Islands and in the region of Catalonia and Galicia. The company has a presence in 12 countries; last year it began operating the first wind farm in Chile. It also recently signed an agreement with another of the largest developers in Spain—Enerfin, part of the Elecnor group—to jointly develop offshore wind parks in southern Spain.

"We're trying to optimize the management system and the design so that the energy we produce is the most efficient possible," says Fernando Ferrando, Endesa's director of renewable energy.

For the past two years, Endesa has sponsored a research award, open to universities, laboratories, private individuals, and businesses, for work on sustainable technologies and energy sources that minimize climate change. The four 2007 winners, from Spain, Italy, and Chile, each receive 500,000 euros (about \$771,000) and access to the company's expertise in business development. One of the winners, a team including researchers from the Autono-



Engineers monitor real-time operations of wind farms in 19 countries around the world from one central location outside of Madrid.

mous University of Barcelona and the Spanish Council for Scientific Research, focused on reducing energy loss and increasing transmission capacity in the grid.

BUILDING THE MACHINES

Another large wind-farm operator within Spain is Acciona, which is also one the top 10 turbine manufacturers in the world. The company's renewable-energy portfolio includes photovoltaic and solar thermal energy, small hydraulic systems, biomass, and nearly 5,300 megawatts of wind power.

Acciona's involvement in turbine manufacturing began in 1994, when EHN (a company Acciona later bought) installed the first wind turbines in the autonomous region of Navarra, beginning with six machines near the capital city of Pamplona. Ever since, the company has worked to make its machines bigger, more efficient, and more reliable while improving their connections to the grid.

One of Acciona's most significant lines of research involves offshore wind farms, which pose distinct challenges in Spain. The offshore turbines in use or in development today stand in relatively shallow stretches of ocean. But Spain's coast drops off precipitously, and siting turbines in deep water raises technological problems that have not yet been solved.

The government recently authorized the development of wind power in selected areas off Spain's coasts and released plans to identify the most promising locations and then work with companies to develop those sites.

Researchers are designing buoys to measure meteorological information in selected areas, boats to service the machinery, and platforms to support the turbines. Platforms with a fixed foundation will work only up to a certain depth, at which point floating platforms, similar to those that support oil rigs, will be

necessary. So far there are no full-scale working prototypes of floating wind turbines.

"The foundation is quite expensive—about 30 to 35 percent of the total cost of the turbine," says Carlos Itoiz, deputy executive director of renewable-technology development at Acciona. "If you mount a small machine, the cost is prohibitive. We need much larger machines to make these systems profitable."

In addition to working on the infrastructure for such systems—no small task, considering that the equipment must survive the punishing ocean environment and then transfer the power to shore—the company is developing offshore turbines with even more power, along the lines of 5 to 10 megawatts. This work necessitates still more improvements. For instance, current power cables carry energy at 132 kilovolts, but Itoiz says that larger machines and larger wind farms will require cables that can carry 220 to 400 kilovolts.

While Acciona doesn't design each part of its turbines, "we have to coordinate all of it," says Itoiz. "We work with an entire network of providers, as basically an extension of our research projects. We don't develop the cables, but we tell the companies what we need and work with them to design it." Some Spanish companies that provide those parts nationally and internationally include Ingeteam, which designs and implements the electric and electronic components of turbines, and Coiper/Comonor, which builds turbine towers. Ingeteam had supplied more than 11,000 wind power converter units as of February 2008, accounting for approximately 16 percent of the global market.

Itoiz says that Acciona plans on continuing to pioneer in this field. "Working offshore provides a number of different opportunities for research," he says. "Wind blows more steadily with less turbulence, so you might be able to use another form of wind-farm

Spanish turbine manufacturers have expanded globally, distributing to more than 25 countries in America, Europe, and Asia.



control; the speed of the rotors might be higher; you don't have to worry about noise [as developers must when onshore turbines are placed near homes]. Everything has to be more reliable, because maintenance is more challenging. You have to work on all these aspects to make offshore wind a success.”

Meanwhile, Acciona is also developing a line of larger land-based turbines—three megawatts, versus 1.5 in the current line. The company has constructed the first prototype and is testing its performance.

One of the major challenges in developing larger turbines is that larger blades are brittle, and their size makes them almost prohibitively difficult to transport. One option is to create blades in sections that could be put together on the wind farm.

Another enduring challenge for wind power in general is how to capture energy during windy periods and store it for later use. The government of Galicia is exploring this question at Sotavento, an experimental wind farm it created in cooperation with a number of local and national companies. One project focuses on using wind power to split water into hydrogen and oxygen in an electrolyzer; the hydrogen can then be used in fuel cells. Acciona is involved in similar research; the company coordinates Wind-hy, a 1.5-megawatt utility-scale wind-hydrogen integration research project. Acciona plans to focus on producing hydrogen for use in fuel cells and transportation.

The largest turbine manufacturer in Spain, and the second largest in the world, remains Gamesa. The company began manufac-

turing turbines in 1995 and today heads a number of research and development projects in the European wind sector. One, called Reliawind, is aimed at optimizing wind systems; Gamesa is leading a coalition of 10 European partners in the venture and has invested 7.7 million euros (nearly \$12 million).

“We want to develop the next generation of wind turbines,” says Ricardo Elorza, a spokesperson for Gamesa. “We want to reduce the cost of maintenance and build more efficient machines. Our goal is to finish Reliawind in 2010.”

Through its work with another European research project, Upwind, Gamesa is joining in efforts to develop larger turbines. The G10, an in-house prototype under development, will produce 4.5 megawatts. Researchers have been improving a control system that minimizes blade vibration and reduces blade load, making the system more efficient and better suited to use in a larger machine. Engineers are also developing a sectioned blade that can be delivered in parts and then reconstructed, thus overcoming the transportation challenge. In addition, researchers are refining a converter technology that will adapt to grid conditions in any country.

Like wind-farm operators, Spanish turbine manufacturers continue to expand their international presence. Gamesa sells turbines in more than 25 countries in North and South America, Europe, and Asia; it opened four new production centers in Pennsylvania in 2006. Acciona opened its first North American turbine production plant in Iowa in January 2008.

Says Elorza, “Wind power is exceeding every expectation. You plan for a growth of 15 percent and the market grows at 30 percent. And Gamesa is growing even more quickly than the market itself, so we are in a very good position.”

The engineering company MTorres, which specializes in aeronautics, has turned its sights to wind turbines as well. In an attempt to reduce the weight of larger machines, the company has developed a new model that operates without a gearbox. “This will improve the endurance of the wind turbine and ease maintenance,” says Emilio Martin, sales director of the MTorres wind division. This technology is also designed to adapt to different grid codes, so the turbines could be used in different countries.

In addition, MTorres is capitalizing on its experience with composite materials, which are often used to reduce weight in planes; turbine blades made from these composites could be much lighter. Finally, the company is exploring whether a small offshore wind turbine could be coupled with a desalination plant to provide fresh water to coastal communities.

WIND BASE

The autonomous region of Navarra, home to some of the major Spanish international wind companies, is also at the forefront of renewable-energy implementation and research. The region can at times meet up to 70 percent of its inhabitants’ electricity needs with renewable energy, the largest portion of it coming from wind. Wind turbines dot the low mountains that extend throughout the region, a skyline of gracefully rotating white blades.

Navarra is also home to the Center for Renewable Energy Research (CENER), which opened in 2002 to conduct research and provide testing and services for client companies. (Though it focuses on wind power, CENER also investigates biomass, solar thermal, and photovoltaic power.) Services might include testing blades to assess their field performance, or mapping wind

resources and forecasting. Thirty percent of the funding comes from national and local government grants; the rest is raised from services and testing for business clients.

Says CENER director Juan Ormazabal, “We wanted to provide companies the services that they required. And sometimes we moved ahead faster than they themselves did, because if we didn’t put ourselves ahead of their needs, we wouldn’t be able to offer value as a research center.”

In the spirit of anticipating client needs, in early 2008 CENER opened the doors to its new wind research center, the largest facility of its kind in the world. It is equipped to test the performance of machines up to eight megawatts, which are currently on the drawing board.

The massive facilities, located about 30 miles outside the Pamplona headquarters, allow researchers to test blade fatigue, gearbox functions, and grid connections. They can simulate conditions to age the machines the equivalent of 20 years in only six months. The site also includes outdoor space where companies can test full turbine assemblies.

At this facility, Gamesa and Ecotécnia partner in the project Windlider 2015, which aims to analyze blade performance and a variety of components for cutting-edge larger machines. Their goals include cutting the development time for new turbines nearly in half and reducing the energy required to produce them by 30 percent. By 2009 the companies plan to be testing 4.5-megawatt machines.

Companies don’t have on-site facilities to perform this type of testing or assembly, says CENER business manager Jerónimo Camacho. “So they have to go to the wind farms, and that can cause several problems,” he says. “The wind farms are very far, and they’re usually not in a very friendly environment. And you need to set up many components, and you have to wait for the wind. So the tests can take a lot of time.” To help address that problem,

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Source: GWEC/AEE/IDAE/REE

Market Snapshot

• Total capacity by end of 2007.....	15,145 MW	• Contribution to national power supply in 2007.....	9.5%
• A record new capacity installed in 2007.....	3,522 MW	• Peak contribution to Spanish electricity supply.....	28%
• Growth rate 2006–2007.....	30.3%	• Equivalent number of households supplied.....	8.4M
• Total capacity target for 2010.....	20,155 MW	• Total generation at the end of 2007.....	26,528 GWH

Economic Growth - Employment

• Total jobs in wind industry at the end of 2007.....	45,000	• Total companies in wind industry in 2007.....	500**
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**Approximate

Wind supplied 9.5 percent of all Spanish electricity in 2007.



CENER is now constructing a 30-megawatt experimental wind farm in Navarra.

In addition, CENER works across five continents in emerging markets such as Costa Rica, Panama, and the Dominican Republic, helping set up regulations to facilitate investment in wind farms and then assisting in their development.

“I think that renewable energy is going to have an extremely important growth,” says Ormazabal, “and emerging countries see this as the opportunity to put themselves on the same level as other countries.”

FORECASTING THE FUTURE

Because wind provides power only intermittently, grid operators working to maximize efficiency need to know how much energy will be available at any given time. Under Spanish regulations, wind-farm operators sell their power to the grid and must predict how much wind they will be contributing; the operators pay penalties for inaccurate prediction. (In other national markets, operators are not penalized for these errors.)

The apparent burden this requirement places upon companies has turned into an opportunity. Spanish companies have taken the lead in microsite prediction—forecasting what will happen at a specific turbine, given the meteorological conditions. In fact, 90 percent of Spanish wind farms use prediction services from one

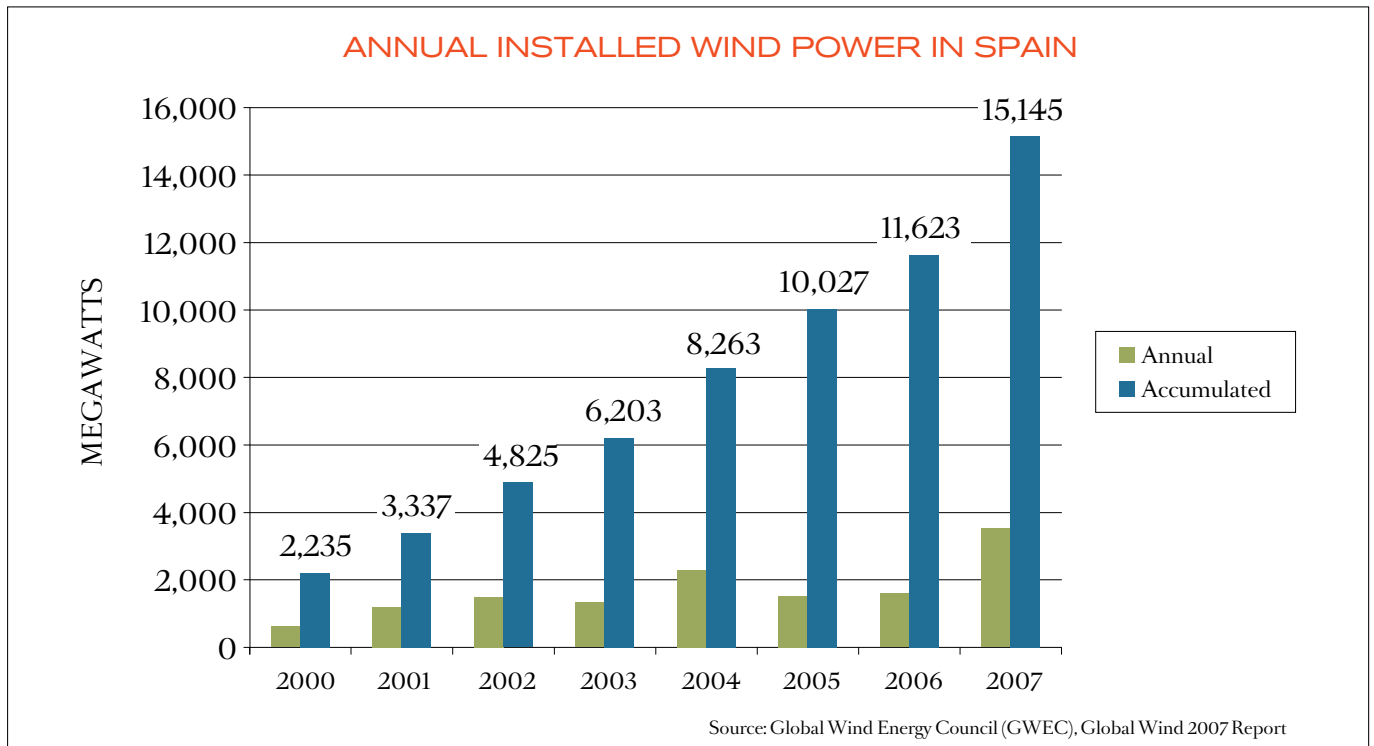
Madrid-based company, Meteológica. The small firm has the largest market share of wind forecasting in the world.

“There was a highly competitive environment, because companies needed to be able to forecast as accurately as possible,” says Manuel Blanco of Meteológica. “In Spain this has made us very successful; we developed a simple system that is able to very accurately forecast the generation of wind farms.”

Meteológica began operations in 1997, developing an automated forecasting system that it began marketing in 2000. Soon the company was providing services for Spanish national and local government offices that needed to predict, for example, agricultural conditions or the chance of forest fires.

“After a few years we started to develop systems to forecast variables of interest to our clients,” says Blanco. The company developed models not just to predict the likelihood of forest fires but to model how those fires would evolve; not only to predict rainfall but to forecast water flows in specific rivers and, thus, hydrological power generation in the country.

Wind power was a natural business evolution. “In 2002 we developed a system that was able to forecast the output of the plant in kilowatt-hours, not just predict the wind speed,” says Blanco. The company began working with four wind farms that year and now manages forecasting for more than 600, predicting outcomes for about 15,000 megawatts of power.



The model works by taking advantage of different global atmospheric models and the meteorological information available from various satellite systems. Engineers input this information along with the conditions on the ground. They have developed statistical models that learn from the wind farm’s actual performance and use that information, coupled with the input, to forecast conditions an hour to two days ahead.

“If a wind farm has been working for the last year, we know every hour how many megawatt-hours it produced,” Blanco says. “So we take this on-the-ground experience and use it with the information from the global atmospheric model. And we’ve developed the statistical relationship, the equation, that translates these atmospheric conditions into generation in megawatts.”

He admits that the model is weakest when a turbine first begins operation and works best after a wind farm has been running for a while. For the first week or two, the company makes its forecasts partly on the basis of simulations from other wind farms, but that’s not necessary for long.

“It has an exponential learning curve,” says Blanco. “In a few months the system has seen almost every atmospheric condition possible on that farm. And a month is nothing in the life of the wind farm”—a typical facility is usually expected to produce power for about 20 years. He says the company has probably improved the accuracy of its wind-power forecast-

ing by about 40 percent since 2003.

Meteológica works with wind farms across Europe and in North America and Asia as well, though international expansion has been cautious and deliberate. Instead of opening marketing offices in a variety of countries, the company attracts new clients through personal meetings and the strength of its track record. All the computations are done from the 17-person office in Madrid.

Another company important in forecasting is Kintech, which provides technology and equipment for collecting meteorological information. Its sensors and data loggers have captured most of the Spanish market, and its devices measure conditions in more than 50 countries. According to general manager Tirso Vasquez, the company has succeeded by customizing remote satellite communications from the data loggers to the customers’ needs.

Systems for understanding wind potential in a given region still have the capacity to get better. To that end, AWS Truewind, an American powerhouse in wind-farm siting and forecasting, joined forces with the Spanish company Meteosim, a spinoff of a meteorological research team at the University of Barcelona. Having honed its technique in small, narrowly focused areas, Meteosim began working with new models for mapping wind resources around the world, providing that information to governments, nonprofit institutions, and potential wind-farm developers.

“Typically the main approach has been to install a tower, wait

for two years, and see how much wind the wind developers or someone has been measuring on that tower,” says Meteosim director Joan Aymami. Instead, Meteosim provides mapping information on specific, narrowly defined sites. “With this approach, a client has a very accurate idea of where to go, where are the best places in a big region.”

ISOLATED SYSTEMS

Spain is something of an energy island; its grid connections with neighboring France and North Africa are weak. Even more isolated are the Spanish Canary Islands, an archipelago of seven small island systems. Nevertheless, the Canary Islands have devoted local resources to investigating the best ways to move wind power into the future. They hope to serve as an example for islands and rural communities around the world.

“In the Canary Islands, the grids are weaker than in Europe, and there are islands around the world with even weaker grids,” says AEE director Alberto Ceña. “The challenge is how to integrate wind with diesel engines or fuel engines. We still need to work a lot on that. The experience of the Canary Islands is going to be very useful in the future of wind power.”

In fact, the islands were, along with Tarifa on Spain’s southernmost border, the site of the country’s first wind farms in the early 1990s. Development slowed, but the local parliament’s 2006 decision to produce 25 percent of the region’s electricity from renewable energy by 2015 spurred an increase in development.

The Canary Islands Institute of Technology (ITC), a regional government research center, has continued working to develop systems that look ahead to the island’s future. “The Canary Islands are a real laboratory and can serve as the ideal platform for testing new energy technologies,” says ITC director Gonzalo Piernavieja.

One recent project involves the island of El Hierro, which has a population of 10,500. The government recently announced a plan that would enable the island to derive 100 percent of its power from renewable sources. The key will be 10 megawatts of wind power connected

to a pump system. When wind blows so fiercely that locals can’t utilize all the energy, the extra power will be used to pump water up a nearby mountain to two reservoirs, one of which is a natural volcanic crater. When the wind drops, the water will fall and turn a turbine. This pumping system has been paired with other forms of electricity, but it’s never been used with wind power before. In addition, the entire system will be connected to a desalination plant to provide potable water.

The dimensions of El Hierro make this small, windy, mountainous desert island the perfect laboratory for testing the new system. Installation will begin within the next year, but Piernavieja says it does offer challenges: “We have to dimension all the electrical protections and wirings, and we have to account for stability in frequency and voltage. This is not a trivial issue in this kind of renewable-energy electricity grid.”

ITC is also working on a system to couple wind power with hydrogen production. A small 10-kilowatt wind-power generator connected to an electrolysis machine was inaugurated in October 2007, along with a larger 100-kilowatt system. “It’s difficult—the components are not easy to manage—but we are learning,” says Piernavieja. “Our main focus of research is coupling the wind energy and hydrogen production systems, because electrolyzers are not meant to work with intermittent power, and there’s no book to read about integration or installation technology.” There are only a handful of such integrated systems in the world.

Says Piernavieja, “We want the islands, particularly the Canary Islands, to be the first hydrogen economies, and the first regions where renewable-energy storage devices are implemented or tested—because islands are kind of showcase of what will happen in continental areas in the future. This is our vision.”

And as the Canary Islands work to become a model for islands and rural areas internationally, so Spain—and Spanish companies—hope to show the world just what the wind might bring.

Resources

ICEX (Spanish Institute for Foreign Trade)
www.us.spainbusiness.com

AEE (Spanish Wind Energy Association)
www.aeolica.org

AEH2 (Spanish Hydrogen Association)
www.aeh2.org

APPA (Association of Producers of Renewable Energies)
www.appa.es

APPICE (Spanish Fuel Cells Association)
www.appice.es

ASIF (Spanish Association of the Photovoltaics Industry)
www.asif.org (in Spanish only)

CIEMAT (Center for Research in Energy, the Environment, and Technology)
www.ciemat.es

IDAE (Institute for Energy Diversification and Savings)
www.idae.es

PSA (Almeria Solar Platform)
www.psa.es

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New Technologies in Spain Series

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As part of this initiative, Technology Review's custom-publishing division has produced the New Technologies in Spain Series, which appears as a special supplement in MIT's Technology Review magazine and a multimedia special section online. This powerful multi-part series showcases the technological development and excellence of Spanish companies in several important industries, such as wind energy, water desalination, high-speed rail, aerospace, industrial machinery, biotechnology, and solar energy.

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