Solar Energy in Spain

Spain is forging ahead with plans to build concentrating solar power plants, establishing the country and Spanish companies as world leaders in the emerging field. At the same time, the number of installed photovoltaic systems is growing exponentially, and researchers continue to explore new ways to promote and improve solar power. This is the seventh in an eight-part series highlighting new technologies in Spain and is produced by Technology Review, Inc.'s custom-publishing division in partnership with the Trade Commission of Spain.

From the road to the Solúcar solar plant outside Seville, drivers can see what appear to be glowing white rays emanating from a tower, piercing the dry air, and alighting upon the upturned faces of the tilted mirror panels below. Appearances, though, are deceiving: those upturned mirrors are actually tracking the sun and radiating its energy onto a blindingly white square at the top of the tower, creating the equivalent of the power of 600 suns. That power is used to vaporize water into steam to power a turbine.

This tower plant uses concentrating solar technology with a central receiver. It's the first commercial central-receiver system in the world.

Spanish companies and research centers are taking the lead in the recent revival of concentrating solar power (CSP), a type of solar thermal power; expanses of mirrors are being assembled around the country. At the same time, Spanish companies are investing in huge photovoltaic (PV) fields, as companies dramatically increase production of PV panels and investigate the next generation of this technology. Spain is already fourth in the world in its use of solar power, and second in Europe, with more than 120 megawatts in about 8,300 installations. Within only the past 10 years, the number of companies working in solar energy has leapt from a couple of dozen to a few hundred.

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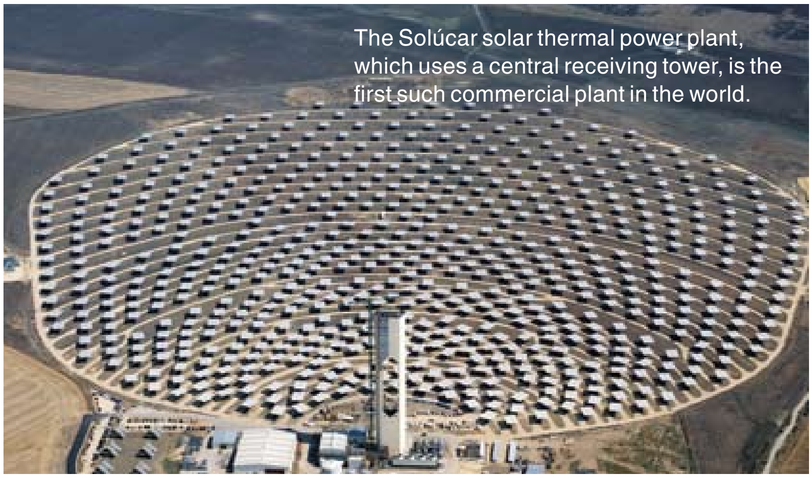
Power from the Sun's Heat

Southern Spain, a region known the world over for its abundant sun and scarce rain, provides an ideal landscape for solar thermal power. The tower outside Seville, built and operated by Solúcar, an Abengoa company, is the first of a number of solar thermal plants and will provide about 10 megawatts of power. The company Sener is completing Andasol 1, the first parabolic-trough plant in Europe—a 50-megawatt system outside Granada that will begin operation in the summer of 2008.

Unlike photovoltaic panels, which harness the movement of electrons between layers of a solar cell when the sun strikes the material, solar thermal power works by utilizing the heat of the sun. CSP has until recently cost nearly twice as much as traditional natural gas or coal power plants, and it is effective only on a large scale. "You need a very large budget to set up a concentrated solar power system," says Eduardo Zarza, director of concentrating solar research at the Solar Platform of Almería (PSA in Spanish), a research, development, and testing center. "You need a great deal of land, a steam turbine, an electricity generator, power equipment, people in the control room, staff to run the system." The costs are also front-loaded, unlike those of traditional plants: the fuel is free, unlike oil, gas, or coal, but the up-front development expense is significantly higher.

During and immediately following the energy crisis of the 1970s, nine solar thermal plants were built in California to produce a total of 350 megawatts, but until this year no new commercial plant had been built, anywhere in the world, for 15 years.

PV costs run nearly double those of solar thermal for a power plant of a similar size, but PV has the advantage of modularity; panels can be incorporated into individual homes, companies,



The Solúcar solar thermal power plant, which uses a central receiving tower, is the first such commercial plant in the world.

“At this plant, we’re working with the potential of about 3,000 suns—so it has to be very well designed and operated to provide the best results.”

and buildings or installed in small spaces. This micropower approach has helped the market for PV explode in the past five years, while solar thermal remained moribund.

With gas costs rising and the world sharpening its focus on global warming, and governments around the world making a concerted attempt to invest in alternative energy sources on a larger scale, solar thermal is attracting new attention. In Spain in particular, the technology has been assisted by Royal Decree 436, implemented in March 2004, which approved a feed-in tariff (a guaranteed price) for solar thermal power. The feed-in tariff made building this type of power plant economically viable. The government also recognizes that, as with wind, support is necessary at the beginning to enable the creation of new plants—which will most likely drive down prices, as has happened in Spain with wind power.

Technologies

The most common technology so far, and the one in use at Andasol 1, is based on a series of parabolic troughs, huge curved mirrors about 18 feet wide that collect the sun’s energy and focus it on a receiver pipe in the middle. Oil streams through that pipe along a long loop of troughs. The mirrors slowly track the sun from east to west during daytime hours, and the oil reaches about 400 ºC (about 750 ºF).

The heat transfer fluid then travels to a steam generator, where the heat is transferred to water, immediately turning the water into steam. That steam powers a turbine, the same technology used in conventional power plants.

The tower technology works on the same principle as the troughs—the sun’s heat—but uses curved mirrors called heliostats, mounted on trackers that shift position with a slight mechanical groan every few seconds. The heliostats direct the sun’s light to a central receiver at the top of the tower. Testing towers have been built in Spain, the United States, and Israel, but the Solúcar PS10 site is the first commercial application of the technology.

At PS10, 624 heliostats, 120 square meters each (nearly 1,300 square feet), concentrate solar radiation at the top of a 115-meter tower (about 377 feet). A receiver at the top transfers the heat directly to water, and the pressurized steam reaches 250 ºC.

The engineering behind such a plant takes into account both the need to heat up the receiver and the importance of moderating the energy directed at it. “At this plant, we’re working with the potential of about 3,000 suns, but the absorption panels can only handle 600 suns,” says Valerio Fernández, head of engineering and commissioning for Solúcar. “We have to control the aiming to protect the solar panels. So it has to be very well designed and operated to provide the best results.”

Fernández says that so far the facility is operating as intended, but improvements will be incorporated into future towers. “This isn’t the best temperature for the highest efficiency,” he says, “but we wanted to test the safety and security of the design for this first installation. We’ll do the remaining research necessary in order to use higher temperatures in future plants.” He explains that the cooling system for the boiler is more complicated as temperatures increase, but that once those changes are implemented, the tower’s efficiency could improve by 20 percent.

The tower is also supported by a small amount of natural gas, used when a stretch of rainy or overcast weather prevents the plant’s full operation and the stored energy cannot stretch far enough to compensate. “It’s good to be able to maintain stability, not be stopping and starting up the turbines more than once a day, as they’re designed to do,” says Fernández.

When completed in 2012, the entire Solúcar facility, called the Sanlúcar La Mayor Solar Platform, will generate more than 300 megawatts of solar power, using tower and trough technologies along with PV installations. Abengoa, owner of Solúcar, has also recently signed plans to build combined-cycle power plants in Algeria and Morocco, using parabolic

PHOTOS COURTESY OF ABENGOA

troughs in conjunction with natural-gas power plants.

One of the main advantages of solar thermal power, in addition to the cost benefit, is the potential for power storage. The Solúcar tower uses a system of heat storage based on pressurized water. Sener's Andasol site will use a more advanced system taking advantage of the specific properties of molten salt. It's been tested in Spain but has not yet been implemented commercially.

Located about an hour outside Granada, home to the world-famous Alhambra, Andasol 1 will provide power well into the evening hours. Sener, which is constructing the plant with a company called Cobra, has built extra troughs that will direct heated oil to 28,000 tons of molten salt (the salt is being imported from Chile). The salt must reach a high enough temperature to liquefy—and then it must be maintained in a liquid state to prevent it from causing blockages. Tubes carrying heated oil will pass through the molten salt, raising the temperature even higher, and the salt will retain the heat energy. As evening falls, the thermal energy will be transferred back to the oil, which will continue on to the heat exchanger and power the steam turbine.

One of Sener's innovations in this field was the development of new simulation software, called Sensol, that takes into account all the variables that go into building a solar plant, determining the production costs and the appropriate dimensions. This technology has also been used outside the country; the Japanese Institute of Technology purchased Sener's services to determine the best dimensions for a solar plant it wanted to develop.

Andasol is Sener's first solar thermal site, though the company has already broken ground on another site nearby, and a third is being planned for a location in the northern part of country.

The company has faced hurdles in building this facility, the first major parabolic-trough system in Spain. "There have been a lot of challenges," says Nora Castañeda, an engineer in charge of the site's construction, laughing. "We can begin with the design itself. It was difficult to find the right manufacturers, because there are so few suppliers of the parts. We had to learn how to assemble a solar field like this in a short time. Once we solved one problem, another appeared."

But as quickly as problems have appeared, she says, the staff worked hard to find solutions. They built an assembly plant on-site and worked with Spanish construction companies to create appropriate jigs with laser trackers for the extremely precise task of building the parabolic mirrors and transporting the system to the field without disruption. Castañeda says she expects the lessons learned from Andasol 1 to help drive down the cost of future systems.

Other companies are part of this rising trend: the Spanish utility giant Iberdrola recently announced plans for 10 parabolic-trough systems across the country.

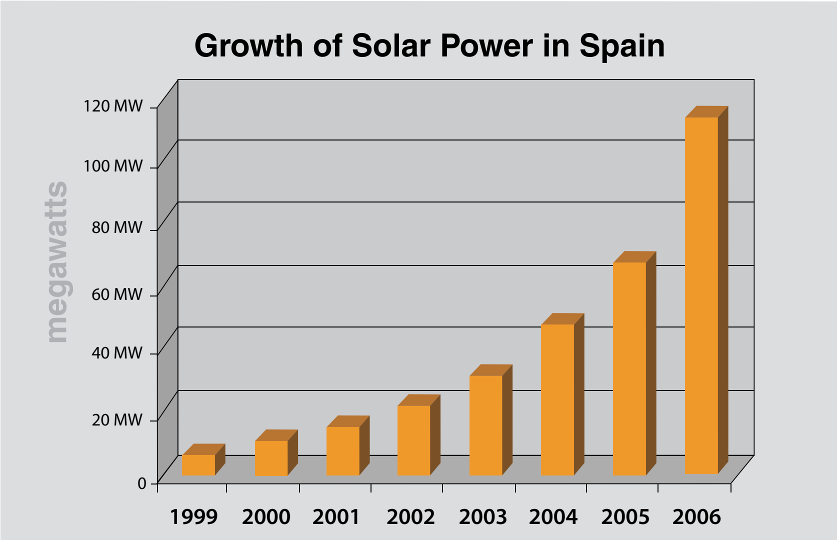
Advancing the Field

Eduardo Zarza is having a great day. In fact, he's having a great year. With a barely suppressed grin, PSA's director of concentrating solar research describes how the center has gone from a research outpost, where he and other researchers toiled away on solar thermal power for 25 years, to an international superstar (at least in certain circles), with near daily visits from companies and scientists from around the world.

Says Zarza, "Every week we have several companies coming to see the facilities to get information, because they're interested in investing in solar thermal plants. The situation has changed dramatically in only two years."

The center, surrounded by dusty rose-colored mountains dotted with green, lies in a particularly dry area, with only 20 percent of Andalusia's average rainfall. Back in the 1970s, with Western countries feeling the pressure of restricted access to oil, a consortium of nine countries—eight European nations and the United States—signed an agreement to investigate two solar technologies: one based on parabolic troughs, the other on a central receiver (like Solúcar's tower receiver).

In 1985, the test results were in: both technologies were commercially feasible, but costs were too high.



SOURCE: ASIF

Since then, the center has continued testing and refining the technology, working with universities and countries around the world. Though there are other research centers with departments dedicated to concentrating solar power, PSA is the largest such research center in the world.

The center is one of two Spanish research facilities that operate as part of what's known as Ciemat (the other, near Madrid, focuses on wind and biomass). Sixty percent of the budget comes from the government, while the other 40 percent comes from grants and industry partnership. Lack of funds threatened the center's operations several times, and it nearly closed.

A rapidly growing interest in renewables, government incentives to promote energy alternatives, and the rising cost of oil and gas placed PSA in the perfect position to take a leading role in the development of renewable energy technologies. After decades in the literal and figurative desert, Zarza finds himself at the center of a renaissance: the technology is finally, once again, entering the marketplace—and the center's activities appear secure and are flourishing.

"We're very happy with the situation now," says Zarza. "In the past, few people wanted to learn about our systems—now, everybody wants to."

Research has focused on technologies to increase the efficiency and decrease the cost of these concentrating solar systems. Reflectors and absorber pipes have been refined, and the coupling between the solar and conventional systems has been improved. The use of molten salt for heat storage was tested on-site before Sener went ahead with plans to install such a system in the new Andasol facility. Researchers also continue partnering with European companies to develop alternative and even more effective storage systems, which could greatly increase solar thermal's viability in the marketplace.

The center is currently investigating replacing heating oil in absorber pipes with water, so the steam turbine could be linked to the solar field directly, bypassing a heat exchanger. "Conceptually, this seems so simple," says Zarza, "but that's not actually the case. Water boils and then turns to steam, and during the transition phase there could be very high temperature differences between the top and bottom of the glass tube, which could cause it to break." Heating oil, unlike water, remains in liquid form throughout the process. Scientists have tinkered with tubes to develop one that can withstand these temperature changes, and soon a new three-megawatt facility will be built at PSA to test it.

Spanish companies continue to innovate in the technology and marketing of photovoltaic power.

PHOTOS COURTESY OF ACCIONA

Fernández of Abengoa's Solúcar, one of the companies participating in the research project, looks forward to replacing heating oil with water. "Oil is expensive," he says, "and in theory you can go to higher temperatures with water and pressurized steam, because oil has a heat limit. It's also more efficient if you can do away with the heat exchanger."

A significant challenge facing developers of CSP plants remains cost—in large part because these plants haven't been built before. Parabolic mirrors must be produced to exacting specifications, and tubes for the oil must be made of two glass layers with a vacuum between them. There's currently one mirror manufacturer in Europe and two manufacturers of the glass tubes, one in Israel and another in Germany. "So when there are more manufacturers producing those tubes, and when there's a larger production in general, you're going to get more competition and a scale advantage," says Peter Duprey, director of Acciona Energy North America, a subsidiary of a Spanish company. He adds, "I think this is at a fairly early stage in its evolution, and with more money and more people focusing on this energy alternative, I think you're going to drive costs down, just like what happened with wind. In the 1980s it was 30 cents per kilowatt-hour; now it's down to about 7 cents. I think you'll see the same thing with concentrating solar."

Both Abengoa and Sener are working with other Spanish companies to jump-start the production of parabolic mirrors and glass tubes in Spain, to increase production, competition, and local access to the necessary parts. At least two local companies will begin producing mirrors within the year, and another few are investigating developing new absorber pipes.

"Electricity costs are going up—and solar thermal costs are going down," says

Parabolic troughs capture the sun's energy to heat synthetic oil at Acciona's Nevada Solar One. That heat will turn water into steam to power a turbine.

Zarza. "We think they will meet somewhere in the middle."

"Electricity costs are going up—and solar thermal costs are going down. We think they will meet somewhere in the middle."

In the U.S.

The first solar thermal power plants in the world, nine in total, were built in Kramer Junction, in dry, sunny southern California, in the 1980s. They still harness 350 megawatts of solar heat. Since the last of those plants was built, however, the technology halted in the United States, as it did in the rest of the world. Research continued at American research centers such as the National Renewable Energy Lab (NREL).

This summer, the first new plant, built by Acciona with technology from the U.S. company Solargenix, came on-line outside Las Vegas in the abundantly sunny Nevada desert.

The Spanish company acquired 55 percent of Solargenix early in 2006 and then began plans to build Nevada Solar One, as the plant is known. The parabolic troughs supply 64 megawatts, enough to power about 14,000 homes annually. Acciona is also in the permitting stage for two 50-megawatt CSP plants in Spain.

Duprey, director of Acciona Energy North America, says, "In the southwest of the U.S. we have plenty of land that effectively is unused, and is near grid connection points. That can be developed, and I think we can get gigawatts worth of concentrating solar power over the next 10 years."

Nevada requires its utilities to generate a percentage of their electricity from renewable sources. The wind is weak in southern Nevada, but the sun burns hot, and the state provided an investment tax credit—so Acciona took on the project.

This type of technology demands vast amounts of land for the parabolic troughs, and the plant is most efficient if it can be sited close to the demand. Conditions in the western United States, particularly the Southwest, meet both those requirements. The Western Governors' Association has stated its commitment to increasing the use of solar thermal power in the region.

Photovoltaics

The growth of solar in Spain is hardly limited to thermal power. Photovoltaic technology is still the primary source of solar power; it has been central to the solar-power repertoire since the 1970s, when researcher Antonio Luque was sent to the United States to share information about microelectronics. He became inspired by American work on PV and returned to Spain, founded the Institute for Solar Research (IES in Spanish) in 1975, and eventually spun off the company Isofotón in 1981. By 1982 the company was already marketing the first Spanish solar cells.

Luque's first contribution to the solar field was the development of bifacial cells, which take advantage of sunlight from both sides. These cells provided Isofotón's start, but higher development and maintenance costs prevented their early adoption, and Isofotón reverted to conventional solar cells.

Today, the 60 researchers at IES—one of the oldest solar centers in the world—continue to push ahead with advances in PV technology. The institute's research areas include multijunction cells that utilize a wider bandwidth of solar energy; intermediate-band cells that can capture lower-energy photons; and concentrator systems in which lenses

PHOTOS COURTESY OF ACCIONA

multiply the sun's energy up to 1,000 times by focusing its light on tiny cells. The last technology is being developed in partnership with Isofotón.

To further develop this new technology, the Institute for Photovoltaic Systems of Concentration is being built in Puertollano, south of Madrid. Companies from Spain, including IES partner Guascor Fotón, will have demonstration sites, along with companies from the United States, Germany, and other countries. The goal is to improve the technology's efficiency and decrease its cost in an effort to speed commercialization.

Luque thinks solar cells will become much cheaper, but he acknowledges that a precipitous drop in price will require technological breakthroughs. He believes these breakthroughs might be occurring already and that the technological advances in store for PV will allow it to easily overtake solar thermal, even on a power-plant scale.

In a huge, airy, light-filled building near Málaga on Spain's southern coast, Luque's spinoff company, Isofotón, hums with the excitement of the exploding PV scene. This factory was completed in 2006, and ground has already been broken next door for an expansion.

The company's production and sales have shot up in the past few years, despite rough patches since its inception in 1981. Isofotón nearly went bankrupt twice as solar power languished worldwide. But in the late 1990s, Germany decided to invest heavily in solar power. Isofotón was able to take advantage of the situation, supplying 15 percent of the German market. It grew to become the seventh-largest producer of solar cells in the world—but the global market has grown rapidly, and a handful of new companies have jumped in to fill the need. Isofotón's rank has now dropped slightly even as its business has expanded dramatically.

Spain has been one of the top world producers of solar cells for the past decade; the two main companies producing those cells are Isofotón and BP Solar, which has been in Spain for more than 20 years and is now planning a major production expansion. In addition, the Spanish company Atersa builds solar panels and provides full solar-power installations. At its new Valencia factory, the company has grown to 14 megawatts of annual capacity and will soon expand to 30 megawatts. Another young solar panel company experiencing rapid growth is Siliken, which is developing a silicon plant to ensure a steady supply of raw materials.

> **"Most of the energy increase in the world will be in electricity, and most of that will be in developing countries."**

Traditionally, Spanish companies have exported about 80 percent of the cells they produced, but with renewed interest in PV within Spain, those numbers are changing. In only the last two years, nearly 100 megawatts of PV power have been added. Isofotón expects to sell about 60 percent of its panels within Spain, though the company still exports to Europe, North and South America, and Asia.

Jesús Alonso, Isofotón's director of research and development, says what distinguishes the company is the high quality of its cells. "You can find information in books about how to make solar cells," he says. "The main difficulty is the know-how—it's how to make sure that those 400 wafers you put in the furnace are actually good, quality solar cells. That's the key."

Like all solar-cell producers, Isofotón has been limited lately by the dearth of highly purified silicon necessary both for microelectronics and the solar industry. In response, it has begun setting up silicon refining operations in Cadiz, which should begin production in 2008.

Working with Antonio Luque's IES, Isofotón has focused its research on developing concentrating PV cells. Downstairs in the factory, in a small room on the main factory floor, a machine whirs as thin sheets of one-millimeter solar cells pass through a machine. The tiny cells will be attached to gold wires and then serve as the focus of the concentrating lenses.

Outside the building, a panel of concentrating PV cells is mounted on a tracker. Unlike standard photovoltaics, which can accept all ambient light, concentrating PV cells are most efficient when tracking the sun to appropriately focus the light through the lenses. Thus, as with solar thermal, the technology will probably be most effective on a large scale, so that fields of trackers can be set up to take advantage of the sun's angled rays.

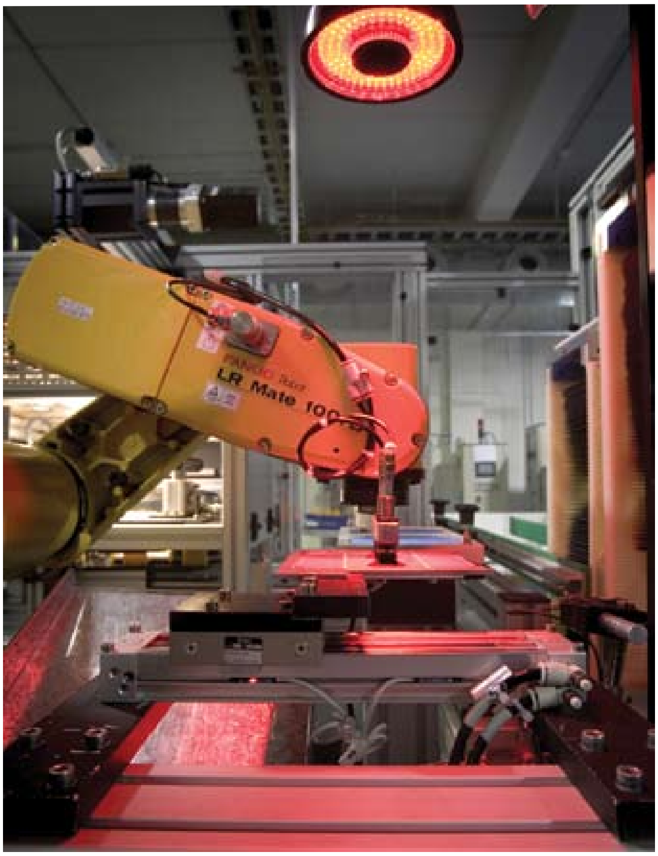
The material used in concentrating photovoltaics is gallium arsenide, which is 50 times as expensive as silicon. But the cells demand just one-thousandth as much material, cutting costs.

When it comes to traditional PV panels, most companies focus on marketing to the developed world—where money is available for PV and the process is as simple as creating the product and selling it. But Isofotón has taken the lead in marketing solar power to the developing world. This year the company expects rural electrification to account for nearly a quarter of its market. Even the marketing works differently for this segment of the business: projects must be researched and appropriate financial models developed for each. Isofotón has rural electrification projects around South America, Morocco, Algeria, Indonesia, and South Africa.

Solar power in these poor, rural regions is not used simply for home electricity but also for applications such as water pumps and desalination. To maintain a lead in this area, Isofotón is not just relying on the decades of experience it has already built up; it's putting additional research into how best to couple solar power with those types of applications, since much of the existing equipment isn't appropriately built to work with an intermittent energy source.

"If we look to the really long term, I think that our main market will be rural electrification, because at the end these are the people who don't have electricity," says research director Alonso. "Most of

Top and bottom left: Isofotón's offices utilize solar power, with PV panels on the building's exterior and solar skylights. **Right**: Isofotón's robots create solar units.



PHOTOS COURTESY OF ISOFOTÓN

the energy increase in the world will be in electricity, and most of that will be in developing countries."

Acciona Solar, the solar-energy arm of Acciona Energía, has seen phenomenal growth rates, as have the other major companies involved in this field. The company's income exploded from about half a million euros to more than 96 million euros in only eight years.

Last December, the company connected the Monte Alto Solar Field to the grid; it's the largest installation of its kind in Spain, and one of the largest in the world. It consists of a field of standard PV panels on trackers (which leads to 30 percent greater efficiency), spread out over a long-disused agricultural field in the southern part of the state of Navarra, about an hour south of Pamplona.

This is the latest of these fields, known as "huertas," or gardens, in Spanish. The 9.5-megawatt facility at Milagro actually has more than 750 owners—investors from across Spain, each of whom owns one or two of the panels and trackers and receives payments from the electric utility.

Most Spaniards live in apartment buildings and share rooftops, so the options for investing in solar power are limited. "This way they can have the same opportunities as the rest of the world even if they don't have their own roof," says Miguel Arrarás, director of Acciona Solar. There are 10 such fields in Spain, of which Milagro is the largest so far, and three more about to enter the construction phase.

The region of Navarra, with local government support, has become a veritable center of renewable energy, with wind turbines arching over the rolling hills and solar fields stretching across open spaces. The region's PV capacity in watt peak per inhabitant is more than 20 times that of Spain as a whole, and nearly double that of Germany, the world solar leader. Seventy percent of Navarra's electricity is generated from wind and solar alone.

Because of this, Navarra has become a perfect site to evaluate the entire system. "We're testing 30 different kinds of panels," says Arrarás. "We also have data on the effects of shadows, fog, everything. We have an agreement with two universities just to analyze this data." He continues, "This is also the perfect place to evaluate what the effect is on the entire grid when, say, there are clouds, because of the high concentration of solar power here."

The company's operations are housed in a zero-emissions building on the outskirts of Pamplona. The building's design incorporates techniques, such as natural light and carefully placed shading, that reduce energy needs by 52 percent compared with those of a typical building. The remaining energy is produced with PV cells, solar water heating, and a small amount of biodiesel. The investments will pay off in 10 years, according to Arrarás. Thanks to the company's experience, Acciona Solar is also researching ways to improve and promote these high-performance buildings.

Acciona is poised to begin construction on a PV solar field in Portugal that will produce nearly 50 megawatts—five times as much as Milagro.

Looking ahead

The Spanish government continues to promote investment in and expansion of both photovoltaic and solar thermal power, with a goal of 400 megawatts of installed power for PV and 500 megawatts for solar thermal by 2010. This still represents only a fraction of the country's total power use and total renewable production.

The government, however, is committed to advancing the sector. The new building code of 2006 requires increased energy efficiency and includes an obligation to meet a significant part of the hot-water demand with passive solar heating. And the Renewable Energy Plan sets a lofty goal of 5 million square feet of solar collectors by 2010. A royal decree approved in May 2007 improves the feed-in tariffs for both solar thermal and PV facilities. Some experts believe that these developments could lead Spain to become the world's second-largest PV market in 2007. Spanish companies and research institutions plan to remain at the forefront of the growing global field.

Says Javier Anta, president of the Spanish Photovoltaic Industry Association, "The solar industry will be a major part of the government's goal of 20 percent renewable energy by 2020. Despite the fact that solar is only a small percentage of renewable power, it's grown more than 100 percent a year in the past few years." In fact, the sector grew 200 percent in 2006. He continues, "We're facing a grand challenge: consolidating that which we've achieved so far, setting the framework for future development, and creating a sector that makes our country proud."

Resources

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

Acciona Energía
www.acciona-energia.com

Atersa
www.atersa.com

Institute for Solar Energy
www.ies.upm.es

Isofotón
www.isofoton.es

SENER
www.sener.es

Siliken
www.siliken.com

Solar Platform of Almería
www.psa.es

Solúcar
www.solucar.es

Spanish Photovoltaic Industry Association
www.asif.org

To find out more about New Technologies in Spain, visit:
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