A mirror alignment device, invented by Rich Diver at Sandia National Laboratories could make parabolic trough collector systems more efficient. The device incorporates theoretical overly photographic technology, or TOP (for more information, see renewable energy focus July/August 2007, page 10).

CSP concentrates the mind

Concentrating Solar Power technology isn't new. But recent high-profile projects – like PS-10 in Spain and Nevada Solar I in the USA – have proven the technology's ability to generate considerable amounts of electricity, and crucially, engage the utilities. Many now believe that CSP's time is upon us. In the first part of a series looking at aspects of CSP and its different technologies, renewable energy focus looks at the **background to CSP**, as well as some of the **current players vying for the top spots**.

Dormant since the early 1990s, Concentrating Solar Power (CSP) is undergoing something of a renaissance in the solar-rich areas of the world, especially Spain and the Southwestern US.

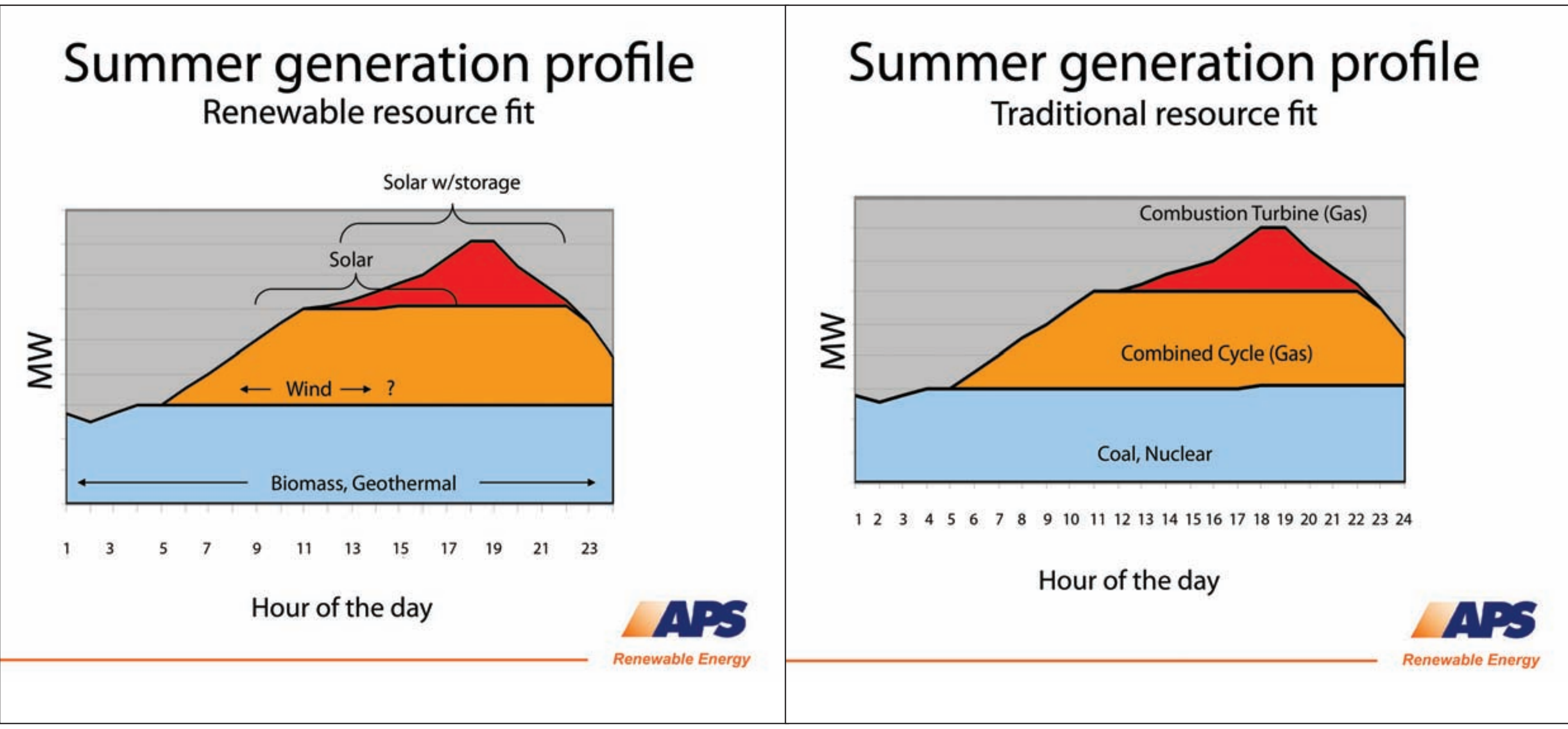
On the face of it, its potential is undoubtedly significant. An international group of scientists and engineers, the Trans-Mediterranean Renewable Energy Cooperation (TREC), say that each square kilometre of hot desert receives solar energy equivalent to 1.5 million barrels of oil.

And the quantities of electricity that would potentially be available are quite startling. It has been calculated that, if it was covered with CSP plants, an area of desert measuring about 25,000 square miles – less than 1% of the area of the Sahara and about half the size of England in the UK – would produce as much electricity as the world currently consumes.

And about one fifth of that area would produce as much electricity as the European Union is using.

In a report published in January 2007, the American Solar Energy Society said that "... analysts evaluated the solar resource in the Southwest [of the USA] and ... found that CSP could provide nearly 7,000 GW of capacity, or about seven times the current total US electric capacity".

What's more, it is already feasible and economic to transmit solar electricity long distances using highly-efficient HVDC transmission lines. A report from the German Aerospace Centre – the 'TRANS-CSP' report – calculates that CSP electricity, imported from the Middle East and North Africa, could become one of the cheapest sources of electricity in Europe, and that takes into account the cost of transmission.



Engaging the utilities – the Arizona perspective: *One value of CSP in Arizona's generation profile is that utilities can potentially rely on it as part of their portfolios. Barbara D. Lockwood of the Arizona Public Service Company explains, "we know that we can count on it and it is productive in the extremely peak parts of the day so it's worth a lot to us".*

Not just plain sailing

CSP will become increasingly attractive to investors as prices fall with refinements in the technology and economies of scale. But even today, investors such as the legendary venture capitalist Vinod Khosla claim that CSP is competitive with clean coal (where CO_2 emissions are stored underground). And large amounts of money are already being invested in CSP.

But there are concerns that need to be addressed. Gennaro De Michele, executive vice president at ENEL Research, says "massive use of solar power will require adaptation of the world's energy system to the new technologies (especially in energy storage and transportation) and new strategies. This implies great opportunities – and, clearly, some risks – for existing companies and operators".

Other concerns centre on the effects that large solar power stations have on fragile desert ecosystems, as well as the perception that CSP might turn out to be another case where rich countries "take what they need from poor countries, and leave little for them except pollution" (though host countries do have much to gain from CSP and several of the benefits are purely local and cannot easily be expropriated).

Proponents of CSP point to the benefits of CSP for host countries in terms of supplies of clean energy; export potential; jobs and earnings; and the by-products that the technology can produce. Waste heat from the steam turbines of CSP plants, for example, may be used for the desalination of sea water, and this would be particularly useful in arid regions where fresh water is scarce. Clearly, there is not much sea water in the middle of the Sahara but large areas of desert around the world are close to the sea and supplies of brackish water may sometimes be found further inland.

Another potentially interesting side-effect of CSP is that the mirrors in the solar field could provide areas of shade that are protected from the harsh glare of the tropical sun. These shaded areas are not totally dark, as there is still plenty of light filtering past the mirror, so it is conceivable that desalinated seawater could be used in combination with this sunlight, allowing green plants to be grown. Thus land that is now unproductive from a human perspective could become a horticultural zone providing food crops and other produce.

Also, since the energy potential of hot deserts is so large, they may provide at least some of what is needed for energy-intensive industrial processes – and it may not always be necessary to convert solar heat into electricity. For example, CSP could provide the large amounts of heat and electricity needed to create aluminium from bauxite, and this could be done in the Australian desert, close to where the bauxite is mined.

With the expansion of CSP around the world and the installation of HVDC Supergrids, there is huge potential to supply the world with clean energy and bring down emissions of CO_2.

CSP technologies

CSP concentrates sunlight using mirrors to create heat, and then uses the heat to raise steam to drive turbines and generators, just like a conventional power station. Plants have been operating successfully in California since the mid 1980s and currently provide power for about 100,000 homes. Quite recently, a new CSP plant went on stream in Nevada, USA (Nevada Solar I) and another one started producing power in Spain (PS10). New plants are now being planned or built in several different places around the world.

There are four major CSP technologies, and there is much healthy debate as to which is the most effective technology (*note – renewable energy focus will cover each of these differing technologies in the next few issues*).

Parabolic Trough

Parabolic trough power plants consist of large parallel arrays of parabolic trough solar collectors which constitute the solar field. The parabolic collector is made of reflectors, each of which focus the sun's radiation on a receiver tube which absorbs the reflected solar energy. The collectors track the sun so that the sun's radiation is continuously focused on the receiver. Parabolic trough is recognised as the most proven technology, and at present experts indicate the cost to be 10 US cents/kWh or less.

Fresnel Mirror technology

The 'Fresnel mirror' type of CSP system is broadly similar to parabolic trough systems but instead of using trough-shaped mirrors that track the sun, it uses long flat mirrors at different angles that have the effect of focusing sunlight on one or more pipes containing heat-collecting fluid which are mounted above the mirrors. As with parabolic trough systems, the mirrors change their orientation throughout the day so that sunlight is always concentrated on the heat-collecting pipe.

The relative simplicity of this type of system means that it is likely to be relatively cheap to manufacture. Another apparent advantage is that mirrors of Fresnel mirror systems lend themselves very well to being integrated in the roofs of buildings, so that their shade can help to keep buildings cool. And the shaded areas under the mirrors, protected from the full glare of the tropical sun, could be good places for growing plants. Several companies are now specialising in the production and installation of this kind of system.

Power towers

While parabolic trough technology is well proven, proponents of the solar tower argue that this is the future.

Power towers consist of a tower surrounded by a large array of heliostats, which are mirrors that track the sun and reflect its rays onto the receiver at the top of the tower. Power towers also reportedly have higher conversion efficiencies than parabolic trough systems. They are projected to be cheaper than trough and dish systems, but a lack of commercial experience means that there are significant technical and financial risks in deploying this technology now.

As for cost, it is predicted that with higher efficiencies, 7-8 cents/kWh may be possible. But it is still early days for the technology's development.

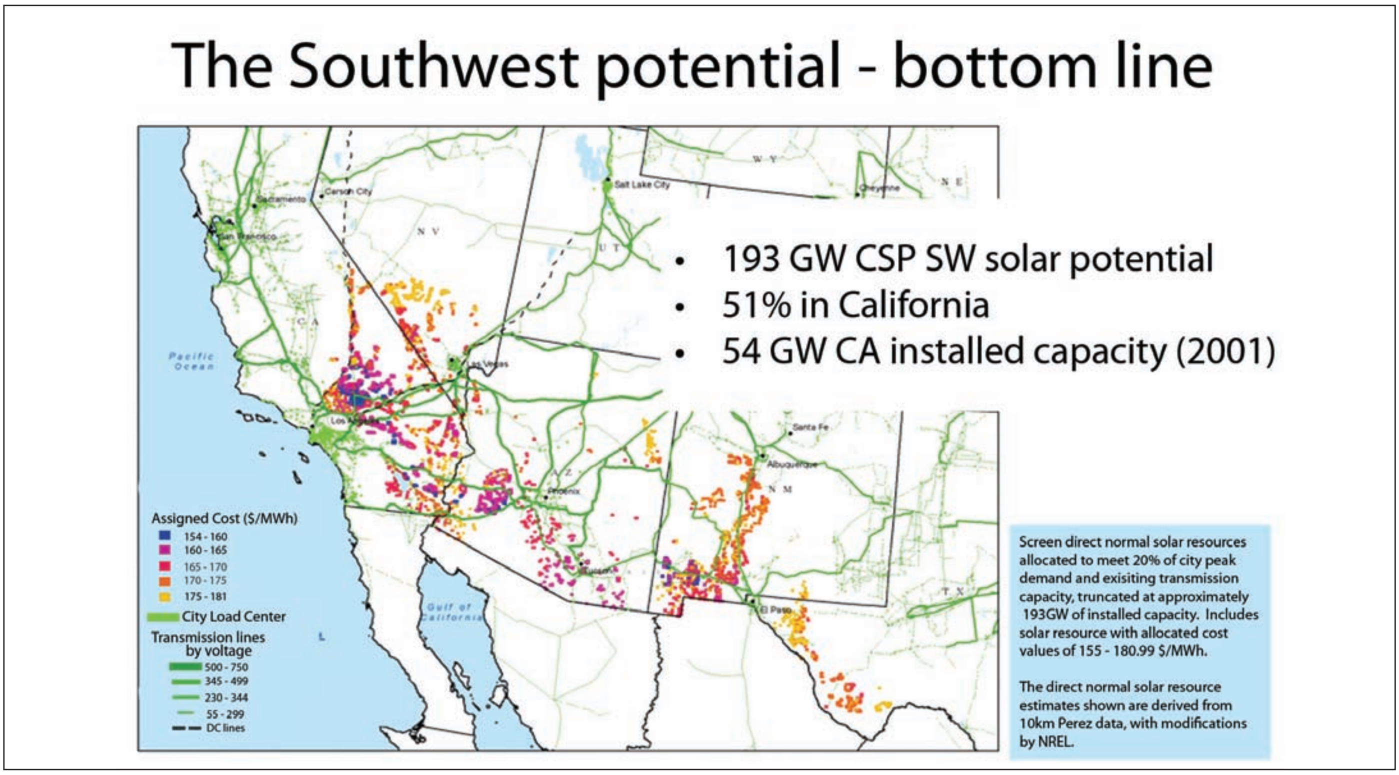
Another feature of both these technologies (Parabolic Trough and the Power Tower) is that it is possible to store solar heat in melted salts so that electricity generation may continue at night or on cloudy days. This is currently much cheaper than storing electricity. It is also possible to use gas as a stop-gap source of heat when there is not enough sun. Heat storage and hybridisation with gas firing allows CSP plants to provide base-load power, and they can also respond flexibly to peaks in demand.

Dish/Stirling-engine systems and concentrating PV (CPV) systems

Solar dish systems consist of a dish-shaped concentrator (like a satellite dish) that reflects solar radiation onto a receiver mounted at the focal point. The receiver may be a Stirling engine and generator (dish/engine systems) or it may be a type of PV panel that has been designed to withstand high temperatures (CPV systems).

Dish systems can often achieve higher efficiencies than parabolic trough systems partly because of the higher level of solar concentration at the focal point. Dish systems are sometimes said to be more suitable for stand-alone, small power systems due to their modularity but there is no reason why they should not be installed in large numbers in desert regions where they could generate large amounts of electricity.

Compared with ordinary PV panels, CPV has the advantage that smaller areas of PV are needed and, since PV is still relatively expensive, this can mean useful savings in costs.



"The US is blessed with some of the best solar radiation on earth; what matters is the intensity of the beam radiation, and there's little moisture in the desert areas," says Fred Morse, a well-respected solar expert based in the USA – slide courtesy of NREL (National Renewable Energy Laboratory).

Europe's first commercial concentrating PS10 solar power tower is operating near the sunny southern Spanish city of Seville. The 11 MW solar power tower produces electricity with 624 large movable mirrors called heliostats.

Unlike thermal CSP systems (parabolic trough, Fresnel mirror, or power tower), dish/engine systems and CPV systems do not lend themselves very well to the storage of solar energy in the form of heat and they are not well suited to hybridisation with gas firing. This means they are less able to provide dispatchable power – unless or until there are methods for storing electricity that can compete in price with the relative cheapness of storing solar heat.

Hotspots for CSP activity

Potentially, CSP technology could be deployed in many countries – South West USA, Spain, Algeria, Morocco, South Africa, Israel, India, and China for example.

Currently, it is in Spain and the South Western USA where much of the commercial, large-scale activity is taking place. The Spanish government has realised the huge potential of the industry and is subsidising the electricity produced through a feed-in tariff scheme. Seville, in Spain, hosts the first commercial plants built for 20 years – Abengoa's PS10 and PS20; when both these plants become fully operational, they will provide energy for 200,000 people.

CSP in the USA

Many are also excited about the potential that the US has to advance CSP technology. Solar radiation in States like California, Arizona, Nevada, New Mexico, Colorado, some of Utah, and Texas could be tapped for CSP generation plants.

But the technology's supporters say federal and state policy measures are needed to help scale up production and lower costs. Long term extension of existing incentives is critical to getting plants built and maintaining the necessary momentum; this is something that the current Federal Energy Bill in the US seems to have overlooked.

Also, for serious CSP expansion, say experts, utility ownership must be an option, making the current utility exclusion from the investment tax credit (ITC) a barrier to CSP.

In fact, it is the utilities who have much to gain from CSP-generated electricity. Firstly, it is despatchable – some of the technologies can store the thermal energy to provide electricity when the sun is not available, and hybridisation with gas-firing can provide a stop-gap source of heat when there is not enough sun; secondly, utilities are familiar and happy with solar steam generation; thirdly, suitability for utility scale installations is 100MW or more – achievable by CSP plants; and finally, stable and known costs (and zero emissions) provide a hedge against natural gas price volatility and future carbon caps.

Some people counter that CSP can't be cost competitive with windpower, for example, but for some utilities that is actually not the major issue; wind "prices" (per kWh) may currently be cheaper but it is difficult to compare as it depends on the "value" of the technology to the utility, and the reliability/despatchability that can be factored in.

One example is in Arizona, explains Barbara D. Lockwood, manager – renewable energy at the Arizona Public Service Company (APS):

"The value of energy is not a straightforward calculation. With solar for example, we know that we can count on it and it is producing in the extremely peak parts of the day so it's worth a whole lot more to us. The cost gap is not linear – you can't just subtract the price of wind from the price of solar and say 'it's that much cheaper' and conclude that 'that's what the value is.' The value of wind is generally less than the value of solar because solar

CSP – where did it all begin?

- In 212 BC, Archimedes used polished bronze shields to focus sunlight, trying to set fire to wooden ships from the Roman Empire which were besieging Syracuse. And today, CSP works pretty much the same way;
- In the 1980's Luz International constructed 9 Solar Electric Generating Systems in the California Mojave Desert; this still constitutes the world's largest solar power plant with a total capacity of 354 MW. All the Luz International plants use parabolic trough collectors. Their success and durability over the past 20 years has demonstrated the robustness and reliability of the parabolic trough technology;
- Luz went bankrupt, and this put a lot of people on guard about the economic prospects of CSP plants, and could have been a major cause for the dormant period from 1991 until fairly recently – during which no new CSP plants were built;
- The dormant period finally appears to be over with the recent PS10 project (constructed in Spain by Solucar) and Nevada Solar I from Solargenix (a subsidiary of Acciona Energía based in Spain), which began service in 2007. The 64 MW plant uses parabolic through technologies and provides energy to Las Vegas;
- And there are several other projects currently in the pipeline too. In USA, Stirling Energy Systems has secured several deals, and will be building the world's first utility-scale dish/Stirling-engine plants. Solel, an Israeli company has also secured a project with utility PG&E to construct a CSP plant;
- Solar Millennium, a German company specialising in the construction of solar thermal power plants, has entered into an agreement with the Spain-based construction company ACS/Cobra group to build two 50 MW solar parabolic trough plants in Spain. Andasol 1 and 2 together will serve the energy needs of about 50,000 households.

produces power during periods of high demand. However, wind does offset our fuel costs for the other resources that back up that wind energy".

The future – establishing the right framework of regulations and incentives

So what needs to happen to drive forward CSP technology?

The cost of electricity is dependant on many aspects of the whole project right from the outset, points out Fred Morse, a well-respected solar expert based in the USA. It needs to take into account factors such as interest rates; what terms the banks want; what the debt/equity ratio is; what the solar radiation is; and what the actually technology used is, to name a few. But if things are "lined up well", Morse believes that the costs will quickly come down: "Studies done by the US DOE and other organisations say that once you build a few thousand megawatts, that price goes down to where that gap disappears".

Thermal storage also improves the competitiveness of CSP plants because it allows the heat to be stored – to be used during the night or during overcast periods when there is no sun. Potentially the most important benefit of thermal storage is the displaced cost of an additional peaking plant. This lowers the cost of the energy produced greatly, and is another reason why utilities are attracted to this technology. Using thermal storage it is possible to shift the output to make sure demand is met outside the hours when the sun shines. "Concentrating Solar Power can be provided as firm despatchable power using thermal storage at a cost per kWh under US$0.10 for deployments over 50 MW in plant size and under US$0.09 for deployments over 200MW in size", says John S. O'Donnell.

If thermal storage is incorporated, the price of plants goes down, say proponents, even though the plant needs to be bigger and is therefore more expensive to build. Thermal storage allows an operator to get more use out of the power plant i.e. more generation, and it means that electricity can be delivered at times when it fetches a good price. So it's up to the utility to decide how much power it needs, and balance the CAPEX and output accordingly.

But probably the main obstacle to the more rapid uptake of these technologies is lack of awareness by investors, decision makers, politicians and the general public. One consequence of this lack of awareness is inappropriate decisions being made by politicians and failure of politicians to provide a framework of regulations and incentives that are appropriate to bring things forward.

But in general, experts are optimistic about the future: "This is a technology the utilities are comfortable with, it has proven reliability, and it lends itself to economies of scale," says Chuck Kutscher, principal engineer and group manager, NREL.

"There clearly is still some room for price reduction, but if we want to get serious about reducing CO_2 emissions and lower our use of fossil fuels, this is a way to quickly address that".

Wind players target the CSP market

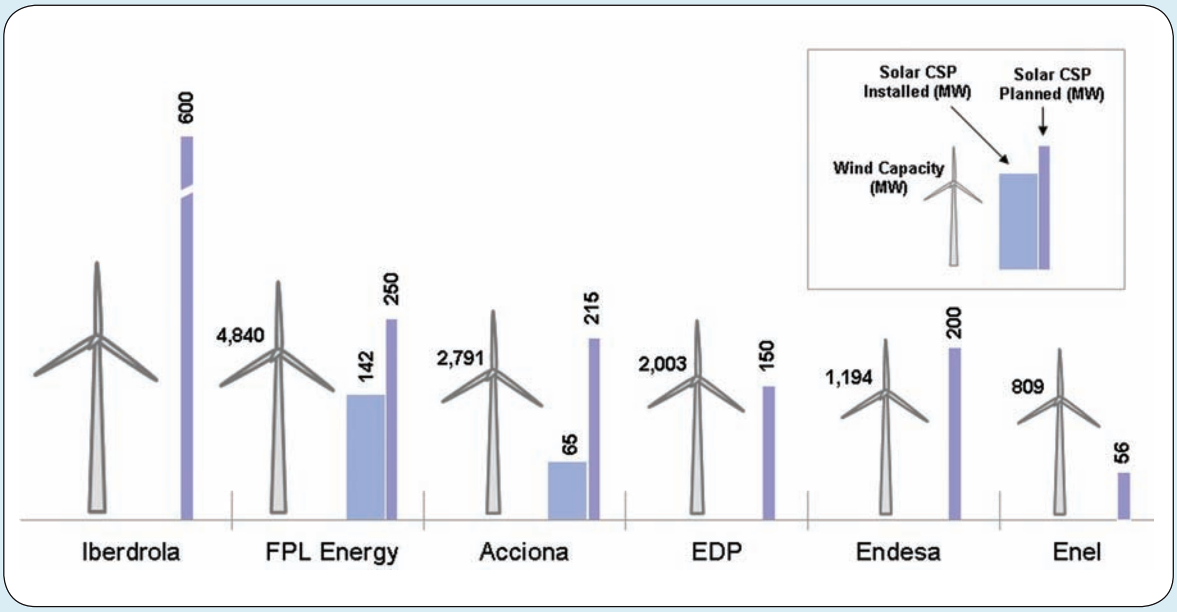
So how is the attractiveness of CSP technology manifesting itself with activity in the sector?

As the renaissance of CSP gathers pace, especially in Spain and the South-western US, there has been a proliferation of new entrants up and down the value chain – ranging from technology innovators looking to change the economics of CSP to investors and IPPs looking to gain first-mover advantages by tying up sites.

It comes as little surprise that the largest owners of windpower plants globally are emerging as significant players in the CSP sector. These participants include US based FPL Energy, which already operates the bulk of existing global solar CSP capacity; Iberdrola in Spain, which has amassed the largest pipeline of Spanish CSP projects; and Acciona, which is active in both markets and which in 2007 put into service the largest CSP project to go online since the early SEGS plants developed by LUZ. However, these leading renewable IPPs and utilities must balance the drive to build MW with a requisite patience for the value chain to settle.

Unlike the early days of windpower development, however, the solar CSP market is emerging amidst a raging appetite for utility-scale renewable power generation projects. With windpower development maturing, IPPs and green utilities are looking for alternatives and CSP projects offering attributes that set them apart from competing renewables technologies, including the ability to scale, relatively proven technology and zero fuel requirements.

As the industry evolves we can expect both horizontal and vertical movement along the project value chain by the well financed utilities and IPPs. Whereas technology promoters will fill out project execution capabilities, utilities and IPPs will build upstream project pipelines and technology capabilities. With growing ranks of new entrants at both ends and across



Wind IPPs and utilities targeting CSP – November 2007 (Source: Emerging Energy Research)

the spectrum, the result is sure to be more confusion in the years ahead as well as in the near term, with a slow settling period as mergers, acquisitions, and business failures narrow the field.

Largest wind plant owners look to solar CSP for next stage of growth

To date, wind energy has been the most widespread and scaleable option among renewables, with projects now reaching 300 MW to 400 MW. Solar CSP development, on the other hand, has been slow to gain momentum with higher generation costs, but is now finding its way into leading wind developers' pipelines. Southern European wind developers such as Iberdrola, Acciona, and others see opportunity in Spain's €0.26 feed-in tariff along with excellent solar resources. FPL, whose 2006 wind portfolio reached almost 5 GW in 2007, also owns a net 142 MW of the SEGS facilities in southern California.

FPL has long dominated the US wind and solar CSP markets with 4,840 MW and 142 MW of installed capacity, respectively. Today, the company is facing increasing competition on both fronts as the market develops. While the CSP project pipeline increases, FPL has quietly watched a series of PPAs be signed by SES, Acciona, Solel, and Bethel Energy. Similar to its wind strategy, FPL has gained solar experience at the SEGS facilities and can now move across the value chain to develop projects.

On 31 August 2005, Iberdrola announced the development of 12 CSP thermoelectric power plants in 7 different Spanish regions (Andalucía, Castilla La Mancha, Castilla y Leon, Extremadura and Murcia) for a total combined installed power of 450 MW. Since then it has added three more projects to reach 600 MW. The company has begun construction of its 50 MW Puertollano facility in Andalucía. In each of the provinces where the plants are slated, Iberdrola has set up a local company responsible for managing the project. Each plant will be scaled to 50 MW, the maximum capacity eligible for incentives in Spain. With wind development saturating and increasingly competitive, utility-scale solar can play an important role in Iberdrola's renewable plans.

In 2006 Portuguese utility EDP, through renewable subsidiary Neo Energía, made an equity agreement with Solar Millennium AG to purchase 50% of the shares in Andasol 2 and 3, both 50 MW projects in Extremadura and Murcia, Spain. As the markets in Spain and Portugal develop, EDP is expected to take on a greater role in the CSP sector and is expected to add to its 1.1 GW wind portfolio. EDP made a major move into the US market through the acquisition of Horizon Wind Energy, and its 327 MW installed capacity and 1,000 MW planned installation by 2007.

Italian utility Enel's activity has been limited to the planning and development of the ISCC facility. However, recent discussion among Government officials to increase the Italian feed-in tariff for solar CSP will likely drive Enel to make larger moves in the sector. With the most diversified renewable portfolio of the world's top 20 utilities, Enel is expected to add to its wind and geothermal activities.

Endesa and Spanish agricultural giant Ebro Puleva have made a recent entry into the market with the announcement to install four, 50 MW parabolic trough systems on Ebro Puleva land outside of Granada, Spain. Endesa will take on the controlling share of the project. The 200 MW to be installed by 2011 are the first step by Endesa to add to its 1,134 MW of wind. The Spanish utility's move further bolsters the Spanish market with another large-scale player in the mix.

In its nascent stage, the solar CSP industry has numerous challenges to face across the industry spectrum. As a result, the most likely candidates to successfully clear the hurdles are those that have developed large scale projects, have deep pockets, and are capable of weathering regulatory uncertainty. The leading wind IPPs and utilities are expected to continue their renewable growth by moving further into the solar CSP industry.

Next issue – CSP Parabolic Trough technology.

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