Innovation in CSP

Concentrating Solar Power recent articles:

PART 6: IN THIS REVIEW OF CONCENTRATING SOLAR POWER (CSP) DEVELOPMENTS, **ROBERT PALGRAVE** LOOKS AT HOW TECHNOLOGY IS BEING DEVELOPED TO PROVIDE A MORE COMPLETE LOWER COST OFFERING TO THE ELECTRICITY MARKET, AND HOW THE FUTURE FOR CSP INCLUDES NOT JUST POWER GENERATION, BUT ALSO THE PRODUCTION OF GAS AND LIQUID FUELS.

Robert Palgrave

Skyfuel's* SkyTrough *uses* ReflecTech Mirror Film *– a low-cost, highly reflective and shatterproof silvered-polymer film to replace the expensive, heavy and fragile curved-glass mirrors.

The current global economic downturn is likely to make it harder for renewables to compete against cheap coal in particular, as investors and utilities become more risk averse and as credit stays tight.

Therefore, to make real progress in displacing fossil fuel power generation, utility-scale renewable technologies have to become more cost competitive and easier for network operators to incorporate into their grids.

Each renewable technology has its merits, and as the price of carbon fuels increase and as the cost of pollution is factored into conventional generation, we can expect all renewables to become more viable. A mix of renewable technologies is beneficial, but some are perhaps better placed to play a leading role.

Of the developed renewable technologies, Concentrating Solar Power (CSP) is possibly the most adaptable. It can be built in a range of sizes, from a few MW up to several hundred MW. It can be configured with varying levels of storage to suit local weather conditions and to meet the requirements of the local grid operator – CSP's optional heat storage means power can be generated when the sun is not shining. And it can be used in co-firing arrangements where the 'back-end' steam turbines and electrical generation / transmission components are powered by burning gas.

Build costs and ongoing operational costs for CSP are both being improved through optimised system design and better specification of materials. Larger scale manufacture, more modular manufacturing processes and better organised deployment to site are also forecast to drive down the cost significantly.

To store or not to store

Grid operators use a mix of different types of generator with which to balance supply against demand:

- Baseload;
- Load–following;
- Peaking;
- Intermittent.

To maintain stability, they can't include too much intermittent capacity in the mix. But by diversifying the types of renewables in the mix – solar PV, wind, CSP, geothermal, landfill gas, hydropower and marine – as well as by having a geographical spread, utilities can go a long way to full de-carbonisation and still be able to support a fluctuating demand.

And here, energy storage can certainly help. Pumped hydro schemes, flow batteries and compressed air storage systems are proven, but as yet not widely adopted technologies to help smooth the peaks of intermittent generation.

Why? Because converting electrical energy into potential energy or chemical energy in this way, then back again, is inefficient. CSP offers a more elegant and efficient storage mechanism – the high-grade heat captured by its solar collectors can be processed immediately into electrical power, or it can be stored as heat and converted at a later time.

Equipped with storage, a CSP plant is more flexible, allowing power to be produced after dark. Storage is not new, it's always been one of CSP's differentiators, offering the utility "power shifting" and dispatchability to help balance their systems. It also allows parabolic trough projects to achieve capacity factors greater than 50%.

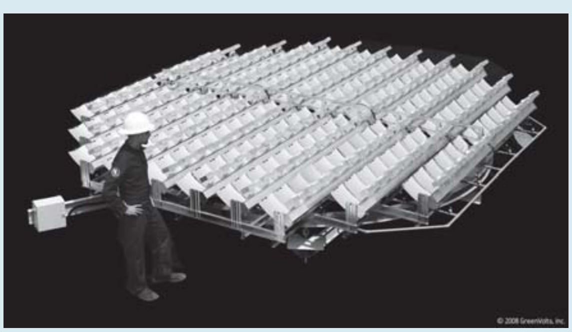
The first **Luz** parabolic trough plant, *SEGS I*, in California included a direct two-tank thermal energy storage system with 3 hours of full-load storage capacity.

The *Solar Two* experimental system built in the 1990s in New Mexico by **Sandia**, routinely produced electricity during cloudy weather and at night. In one demonstration, it delivered power 24 hours per day for nearly 7 straight days before cloudy weather interrupted operation.

Pushing the envelope: three examples of CSP innovation

An excellent recent "CSP technology and markets" conference run by **Greentech media** (http://www.greentechmedia.com) and the **Prometheus Institute for Sustainable Development** (http://www.prometheus.org/) – taking place at Intersolar USA – revealed some interesting examples of innovative development in CSP:

- **Skyfuel Inc** has unveiled the *SkyTrough* (*see image on page 44*), a parabolic-shaped concentrating collector. It is patterned – after the best of the prior-generation utility-scale parabolic trough designs – but uses glass-free mirrors, which results in substantial weight and cost reductions, has a highly-engineered space frame that allows compact transportation and rapid field assembly, and new more efficient drive & control systems. Skyfuel reckons its *SkyTrough* cuts the cost of the parabolic trough concentrators by 35% compared to other commercially available systems. It is now the solar collector system at the heart of several large solar thermal power plants currently planned for the southwestern USA. Its *ReflecTech Mirror Film* is a low-cost, highly reflective and shatterproof silvered-polymer film, jointly designed by SkyFuel CTO, Randy Gee, and scientists at NREL to replace the expensive, heavy and fragile curved-glass mirrors (http://www.skyfuel.com);
- **GreenVolts**' state-of-the-art concentrating photovoltaic technology achieves unparalleled solar-to-electricity conversion efficiency through an innovative integration of optics and solar tracking. Like central station power plants, GreenVolts' technology is a complete power plant designed for delivering the lowest levelised cost of energy; yet similar to traditional rooftop solar panels, GreenVolts' power plants are sited close to loads, increasing efficiency and further reducing cost. Greenvolts' idea is that instead of targeting expensive rooftop solar panel projects or building huge, costly, desert-based ST plants, it builds modular urban plants (the *CarouSol* – *see image below*), that can be placed near communities and plugged directly into the existing grid (http://www.greenvolts.com);
- **Ausra**'s core technology, the Compact Linear Fresnel Reflector (CLFR) solar collector and steam generation system has significant advantages in cost and scalability, and the company aims to become the leading CSP producer on the basis of its compact plants and low constructions costs. The organisation continues to work on optics, coatings, materials and manufacturing processes to improve the performance and reduce the cost of solar collector systems, thermal energy storage systems and power plant cooling systems (http://www.ausra.com);



Greenvolts' modular urban plants (the CarouSol*) can be placed near communities and plugged directly into the existing grid.*

The finances of storage

Storage can actually make CSP electricity a more attractive financial proposition:

- **Spreading the delivery of power** – without storage, a CSP plant needs a turbine large enough to handle peak steam production, during the hottest times of the day. Or the solar collector needs to be backed off. With heat storage, a plant can use a smaller, cheaper steam turbine that can be kept running steadily for more hours of the day, and thereby maximise the investment in the solar collector;
- **Concentrating the delivery of power** – with storage, the plant operator can hold back solar energy collected in the morning and dispatch it to the grid when wholesale prices are higher at times of peak demand, typically late afternoon and early evening in markets where air conditioning is prevalent. The power plant has a higher peak electrical output than the solar collector because stored solar energy and real-time solar energy can be fed to the turbine simultaneously.

The developers of the *Andasol 1* plant in Spain say their electricity will cost 11% less to produce than a similar plant without storage, citing figures of €271 / MWh instead of €303 / MWh.

The amount of storage required will vary according to capital availability, and the needs of a given utility. "There is an optimal point that could be three hours of storage or 6 hours of storage, where the cents per kilowatt-hour is the lowest," says Fred Morse, senior advisor for US operations with **Abengoa Solar**. Its 280 MW plant in Arizona, scheduled to be in service in 2011, will have 6 hours of storage, while other recent projects are aiming for 7 or 8.

CSP storage technologies

The most well known variant is the **indirect thermal energy storage** technique – it uses molten potassium and sodium nitrate salt in a two-tank system. Salt from the 'cold tank' is heated by the heat transfer fluid (oil) coming out of the solar collector field, and is then transferred to the 'hot tank'. To recover the stored energy to create steam for the turbine, salt is pumped from the hot tank to the cold tank to reheat the oil. It's referred to as an indirect system because the fluid used as the storage medium is different from that circulated in the solar field.

The *Andasol 1* parabolic trough plant will use this technique to run its 50 MW steam turbine for up to 7.5 hours after dark. Tanks 14 metres high, and 38.5 metres in diameter will store the 28,500 tonnes of molten salt, which provides the necessary heat storage.

Power towers currently have the advantage that it's possible to use the molten salt itself as the heat transfer fluid. Heating the salt directly instead of using oil as an intermediate carrier gives higher efficiency because the salts can be safely heated well beyond the 400° C limit of synthetic heat transfer oils.

With a greater temperature difference between hot and cold (300° C instead of just 130° C), less salt is needed to store the same amount of energy. Expensive heat exchangers are not needed, also helping keep costs down. In Spain, **Abengoa Solar** and **Sener** are each testing solar thermal plants with this form of integrated molten-salt storage, and **SolarReserve** is developing similar systems based on **Rocketdyne**'s molten-salt heat receivers used in the 10 MW power-tower *Solar 2* demo plant that operated in the early 1990s.

American and Italian researchers have worked on developing molten salt heat transfer fluids suitable for use in the solar field of parabolic trough plants. A key issue is to find a salt that does not freeze in the solar field piping during the night. If successful, it offers the potential for efficiency improvements and cost savings by avoiding heat exchangers.

But for trough plants, some believe that a **single-tank thermocline**-type energy storage system could turn out to be the most cost effective option. In thermocline systems the hot storage fluid is held at the top of a tank with the cold fluid on the bottom. The zone between the hot and cold fluids is called the thermocline. This type of storage system has an additional advantage – much of the storage fluid can be replaced with a low-cost filler material.

Sandia National Laboratories has demonstrated a 2.5 MWh, thermocline storage system with binary molten-salt fluid, and quartzite rock and sand for the filler material.

Other non-salt storage techniques have been developed. The *PS10* power tower near Seville in Spain has relatively small-scale and technically straightforward storage to keep the plant operational during cloudy periods. Its **saturated water thermal storage** system has a thermal capacity of 20 MWh and comprises four tanks that are sequentially operated in relation to their charge status. During full load operation of the plant, some of the steam produced by the saturated steam receiver at the top of the tower is used to load the thermal storage system. When energy is needed to cover a transient period, energy from saturated water is recovered at 20 bar to run the turbine at a 50% partial load.

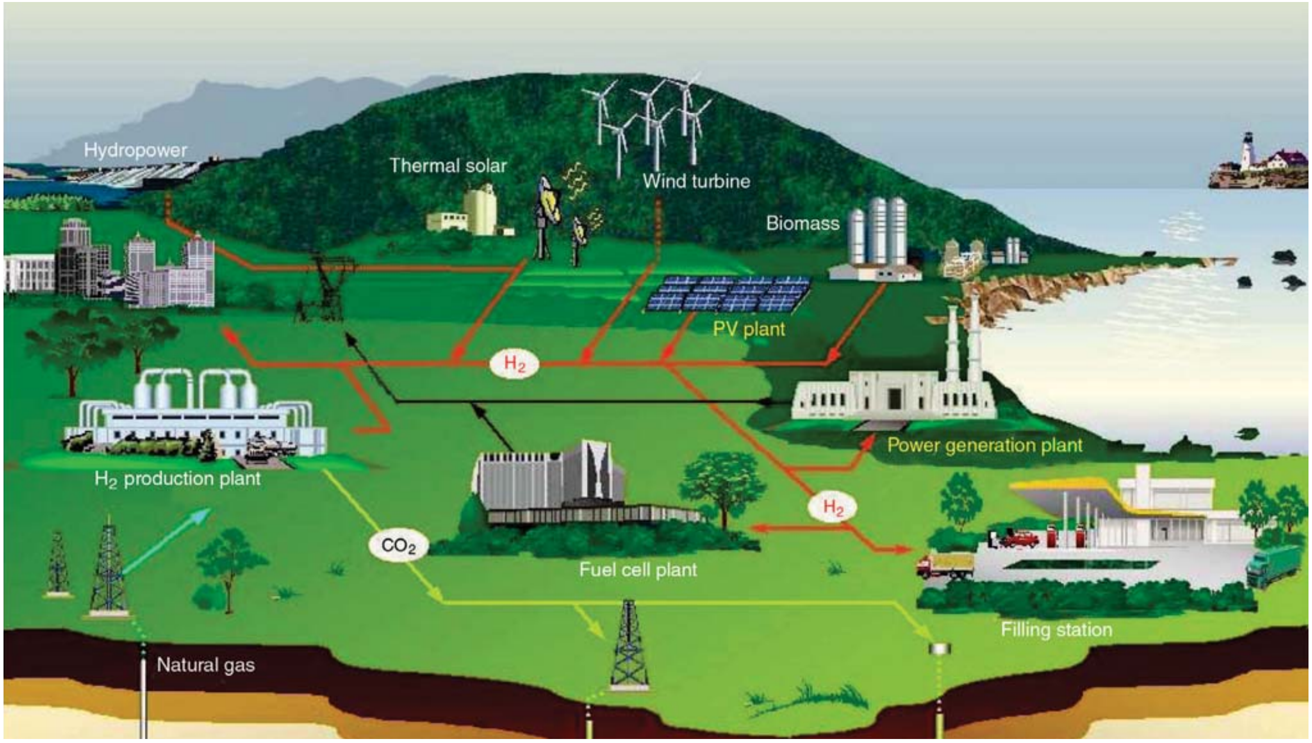
A very different design has emerged from down under. Cloncurry in Queensland Australia is to get a 10 MW Concentrating Solar Power (CSP) power tower plant in early 2010, which will use **graphite blocks** at the focal point of the solar field. Steam is produced by running water through pipes embedded in the 540 tonnes of graphite. This steam (at very high temperatures) is then used to drive the turbine. The heat stored in the graphite will run the turbine at full capacity for 8 hours.

Solid materials for heat storage are also under development for trough power plants. The **German Aerospace Centre (DLR)** is assessing the performance, durability and cost of using high-temperature concrete or castable ceramic materials as the thermal energy storage medium. A standard heat transfer fluid from the solar field passes through an array of pipes imbedded in the solid medium to transfer the thermal energy. The primary advantage of this approach is the low cost of the solid medium compared with molten salt.

A paper design from Professor Reuel Shinnar of **New York's Clean Fuels Institute** takes yet another approach. His proposal for ultra-high efficiency CSP plants is based on the principle that thermal efficiency rises, and cost of power production falls, with increased operating temperature. He reasons that current CSP designs are inefficient because the heat transfer materials and the storage systems currently used can't make use of the high operating temperature that can be achieved by a good solar collector in a region with high insolation.

Shinnar's design uses pressurised gas (he suggests CO_2) as the heat transfer medium flowing in a closed circuit from solar collectors, either directly to the power plant or through heat storage. There is no maximum temperature imposed by the gas itself. His proposed heat storage system uses vessels filled with a heat resistant solid filler, such as alumina pebbles which can operate at temperatures up to 1650 °C. and he claims storage costs would be 3 to 10 times less than using molten salt because of higher thermal efficiency and greater temperature differential.

Phase change materials (PCMs) are yet another option for storing heat from a CSP plant and are considered to be a good candidate for trough plants that use direct steam generation. Heat is absorbed or released when PCMs change from solid to liquid and vice versa. A **DLR / EU** project



Natural power sources working together: the hydrogen vision of the future.

But by diversifying the types of renewables in the mix – solar PV, wind, CSP, geothermal, landfill gas, hydropower and marine – as well as by having a geographical spread, utilities can go a long way to full de-carbonisation and still be able to support a fluctuating demand.

known as *DISTOR* is working to optimise performance through the micro-encapsulation of PCM in a matrix of expanded graphite material.

Solar power without the sun

Storage gives CSP plants the power to produce electricity when sunshine is not available. Co-firing or hybridisation with gas or other fuels also allows the power plant side of the CSP site to be productive up to 24 hours a day.

Plants can be configured so that conventional fuels like gas generate the majority of the power, as for example in the **World-Bank**-funded 150 MW plant at Hassi R'mel, south of Algiers. The plant is due to go into operation in 2009 and has a 25 MW solar energy capacity using a parabolic trough solar collector.

A less conventional approach to co-firing was announced in June this year, when plans appeared for a California Central Valley 100 MW CSP plant **co-fired with agricultural waste and manure**.

The EU research projects *SOLGATE* and *HYPHIRE* have shown that a gas turbine could be modified to allow dual operation from solar and gas, and that solar dish/Stirling engine technology could be adapted to use heat from solar and fossil fuel.

The World Bank has suggested that investors and decision-makers will see hybrid solar-gas plants as being less risky than an all-solar plant, and therefore more likely to attract investment. In theory, as confidence in solar grows, more solar collectors could be added to existing hybrid plants.

Getting to grid parity and beyond

Across the system, measures need to address thermal efficiency, durability, ease of manufacture and on-site construction.

In the solar field itself, developments are targeting the optical performance of mirrors, their longevity, the support structures, the durability of the heat collection elements used in trough systems, and the electrical/electronic systems used to direct heliostats.

Instead of steel for framing its solar troughs, the **Solargenix** collector used at *Nevada Solar One* is made from extruded aluminium. The lower weight collector has a unique organic hubbing structure, initially developed for buildings and bridges. Manufacturing is simplified and no field alignment is needed.

And while most parabolic troughs are made out of glass, **SkyFuel**'s *SkyTroughs* are made from the company's own mylar-like *ReflecTech* film. SkyFuel claims it can bring down the cost of a solar system by 25% with this material. **NREL**'s *Advanced Materials* programme is continuing to assess a range of solar reflector materials including thin glass, thick glass, aluminised reflectors, front-surface mirrors, and silvered polymer mirrors.

But perhaps it is the choice of system design that will ultimately have the biggest impact on cost. Argument rages over the relative merits of the different CSP technologies. Power towers are not restricted by the temperature limits of oil-based heat transfer fluids typically found in trough systems, and can use molten salt or steam as the heat carrier. Advocates claim the increased thermodynamic efficiency will be key. Towers also avoid the miles of precision evacuated glass tubing needed in trough systems. But trough supporters point to the years of accumulated experience as evidence that theirs is a durable, dependable design.

A recent entrant to the power-tower market is **eSolar**. Its strategy is to make prefabricated modular solar-thermal power plants (typically 33 MW) and locate them near towns and cities. Multiple modules could be configured together on one site to increase capacity. Their design uses direct steam generation with relatively short towers, to keep down the cost. Heliostats are small and low to the ground, reducing their wind profile and the company believes high volume manufacturing and reduced installation effort will drive costs further down.

Ausra is another leader in design optimisation for cost. Its Linear Fresnel designs use lower cost mirrors than troughs (see 'CSP: bright future for linear fresnel technology?' Sep/Oct, pages 48–51), and avoid the need for the expensive heliostats inherent in a power tower design.

Solar dish systems using Stirling engines free the utility operator of the need to use large areas of level land, and to provide the CSP plant with a water supply. Israeli company **HelioFocus**' novel design using superheated air as the heat transfer mechanism also avoids the need for a water supply. Its solar receiver collects heat from a parabolic concentrator, and the hot air it produces drives a micro-turbine directly. Meanwhile the *EU SOLAIR* research project is studying how ceramic receiver technology using air as the heat transfer medium could be applied in power tower design.

Is CSP a mature technology?

The extent of the Government-funded research effort, and the number of new market entrants with fresh thinking suggests that there are still opportunities to enhance CSP technology and enhance its appeal to utilities. But CSP's underlying concept is not in doubt – the research and development work happening around the world is essentially evolutionary, and argues strongly that this is a maturing technology with a key role to play in the de-carbonisation of the world economy.

About the author:

Robert Palgrave is a member of the TREC-UK group.