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Renewable Energy Essentials: Concentrating Solar Thermal Power

- Concentrating solar thermal power (CSP) turns sunlight into electricity.
- CSP requires clear skies and strong sunlight, which is abundant in the southwestern United States, Mexico, North Africa, the Middle East, Central Asia, South Africa and Australia. Southern Europe and parts of China and India may also have sufficient solar resources.
- Concentrated solar thermal power provides firm, peak, intermediate or base load capacities due to thermal storage and/or fuel back-up.
- CSP technology showed especially strong growth in Spain and the United States since 2006. Installed capacities near 1 gigawatt (GW) and projects under development or construction exceed 15 GW worldwide.
- Investment costs range from USD 4.2 to 8.4 per watt, depending on the solar resource and the size of the storage. Levelised electricity costs range from US cents 17-25 per kWh, mostly depending on the quality of the solar resource.
- Energy costs are expected to decrease as more suppliers enter the market and as a result of R&D efforts and learning. In good sites, they could break the threshold of US cents 10 in fewer than ten years.
- The BLUE scenario of the IEA publication, *Energy Technology Perspectives 2008*, foresees that CSP will provide 5% of world electricity by 2050. Preliminary results of the forthcoming IEA CSP Roadmap suggest a contribution of 12% to global electricity supply by 2050.

Market status

Recent trends

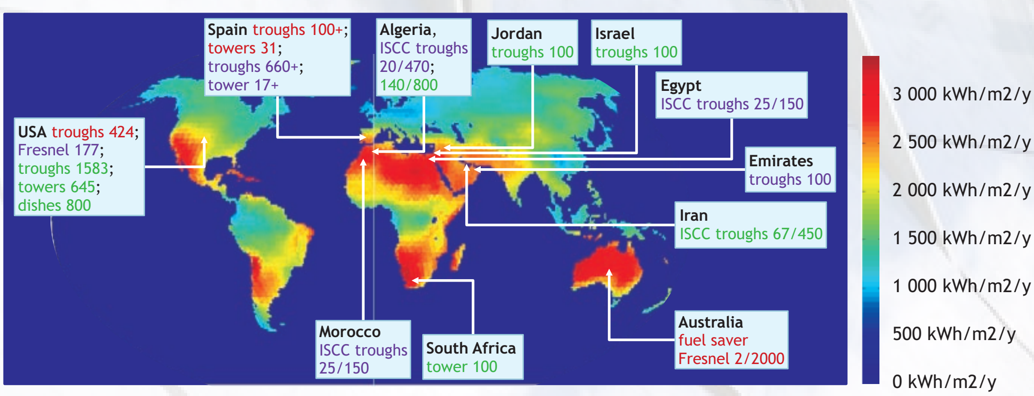
Concentrated solar thermal power (CSP) is a re-emerging market. The Luz Company built 354 MWe of commercial plants in California, still in operations today, during 1984-1991. Activity re-started with the construction of an 11-MW plant in Spain, and a 64-MW plant in Nevada, by 2006. There are currently hundreds of MW under construction, and thousands of MW under development worldwide. Spain and the United States together represent 90% of the market. Algeria, Egypt and Morocco are building integrated solar combined cycle plants, while Australia, China, India, Iran, Israel, Italy, Jordan, Mexico, South Africa and the United Arab Emirates are finalising or considering projects.

While trough technology remains the dominant technology, several important innovations took place over 2007-2009: the first commercial solar towers, the first commercial plants with multi-hour capacities, the first Linear Fresnel Reflector plants went into line.

The solar resource: DNI

Concentrating sunrays requires clear skies, which are usually found in semi-arid, hot regions. The resource is measured as Direct Normal Insolation (DNI), which is the energy received on a (tracking) surface

Figure 1: Direct Normal Insolation in kWh/m².y and on-going projects
Breyer & Kniess 2009, after DLR-ISIS, plus IEA information.



Legend: existing capacities; capacities under construction; announced capacities; xx: capacity in MWe. +: indicates large storage capacities (the capacity of the power plant is larger than the electrical capacity indicated); xx/yy: for Integrated Solar Combined Cycle or fuel saver systems, xx indicates the solar capacity, yy indicates the overall capacity.

perpendicular to the sunrays. Areas suitable to CSP technologies are found between 15° to 40° parallels – and occasionally at higher latitude. The most favourable areas, shown in Figure 1, are found in large parts of North Africa, Middle East, southern Africa, western India, the southwestern United States, Mexico, places in South America, and Australia. Other suitable areas are in the extreme south of Europe and Turkey, central Asian countries, western China. Satellite data and regional climatic mapping must be confirmed with DNI monitoring on the ground.

Manufacturing and employment

The building of CSP plant creates eight to ten jobs per megawatt of equivalent electrical solar capacity in the construction and manufacturing of components.

Economics

Investment costs

For large state-of-the-art trough plants, investment costs are in a range of USD 4.2 to 8.4 per Watt depending on labour and land costs, technologies, the quality of the solar resource (DNI) and the sizes of storage and solar field.

Generation costs

Levelised electricity costs range from USD 170 to 250 per MWh for large trough plants, depending mostly on the solar resource (assumptions: 30 years economic lifetime, 8% discount rate).

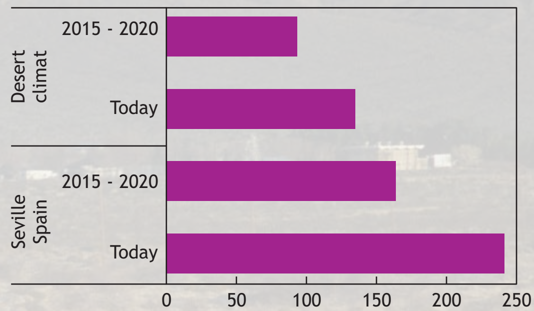
When there is large storage capacity, the investment costs increase significantly with the size of the solar field but so does the electrical output, so the energy cost changes only marginally. If storage serves to extend the production, energy costs will slightly decrease as smaller turbines can be used.

Cost reductions

As cumulative capacities increase, investment costs and energy costs will decrease to an estimated range of USD 97 to 130 per MWh by 2015-2020, assuming learning rates of 12% for the solar-specific investments and of 5% for the power block and balance of plant investments.

Figure 2: Levelised electricity cost from CSP plants

Source: IEA analysis. Assumption: 16 GW global CSP capacity by 2015-2020.



Outlook

Growth drivers

The deployment of CSP plants is driven by feed-in tariffs in Spain, and Renewable Energy Portfolio Standards and a grant programme in the United States. Projects in Egypt and Morocco are supported by grants from the Global Environment Facility. Algeria, South Africa and the Gujarat State in India have also established feed-in tariffs for CSP.

The Mediterranean Solar Plan of the Union for the Mediterranean is likely to initiate a wave of new projects on the south shore of the Mediterranean Sea. Of a total of 20 GW renewable energy capacities expected by 2020, half or more might be CSP plants. Exports of renewable electricity to the European Union would provide a strong incentive.

Barriers

Low costs of fossil fuels remain an important barrier on grid – even more so in countries where fossil fuels prices are kept below world prices by direct or indirect government subsidies. Suitable areas are often semi-arid and water scarcity might be an issue, unless costlier dry cooling is used. Permitting and connection to the grid might also be challenging.

Technical potential

The technical potential for CSP is virtually unlimited. An area of 100 miles squared in Nevada could power the entire US economy. The technical potential of the Middle East and North Africa (MENA) is more than one hundred times the total current electricity consumption of the MENA and European regions together. High voltage direct current (HVDC) transport lines may allow CSP suitable areas to feed energy-demand centres.

Long-term scenarios

In the "Advanced Scenario" of their publication *CSP Global Outlook 2009*, the IEA SolarPACES Programme, the European Solar Thermal Electricity Association and Greenpeace have estimated the global CSP capacity by 2050 at 1500 GW. With large storage and solar fields, the yearly output would be 7 800 TWh, or 670 million tonnes oil equivalent.

In a detailed study of renewable energy potential in the Middle-East North Africa Region, the German Aerospace Center (DLR) has estimated that CSP plants could possibly provide by 2050 about half the region's electrical production, from a total of 390 GW CSP capacities.

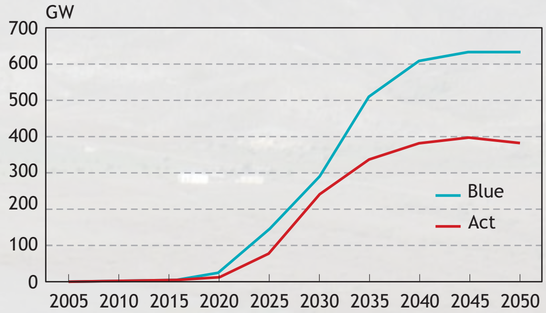


Figure 3: Growth of global renewable electricity production in the BLUE Scenario of ETP 2008

In the Blue Scenario of the IEA publication, *Energy Technology Perspectives* (ETP) *2008*, where global energy-related CO_2 emissions are down to half their 2005 level by 2050, CSP would globally produce 2 200 TWh at the time from a capacity of 630 GW. CSP would thus contribute to about 5% of global electricity production (see Figure 3).

Preliminary results of the forthcoming IEA CSP Roadmap suggest a solar contribution from CSP of 12% to global electricity supply by 2050.

System-related aspects

In regions with suitable solar resources, peak electricity loads are increasingly driven by air-conditioning systems; there is a good match between loads and resources. Further, CSP technologies are usually open to both thermal storage and fuel back-up, offering systemic advantages.

Thermal storage and fuel back-up increase the value of the plant by providing guaranteed capacities. Storage can be used to extend the electricity generation after sunset, when electricity loads remain high. Storage could also serve round-the-clock, base-load generation, displacing, *e.g.* high-CO_2 emitting coal plants.

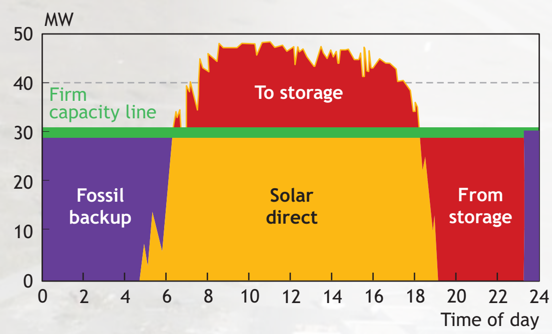


Figure 4: Round-the-clock operation of a CSP plant with storage and back-up

Source: Geyer, SolarPACES Annual Report 2007

Cheap back-up with some fuel can extend the guarantee of full capacity to winter periods – avoiding costly extra-investment in the solar field. This can be especially useful at a system level as other renewable energy technologies (*e.g.* wind turbines) cannot offer guaranteed capacity.

Environmental impacts

Life-cycle emissions

Life-cycle CO_2 emissions of solar-only CSP plants are assessed at 17 g/kWh against, *e.g.*, 776 g/kWh for coal plants and 396 g/kWh for natural gas combined cycle plants.[1] However, to the extent that some fossil fuel is used as a back-up, a CSP plant or an ISCC cannot be qualified as a "zero-emitting" plant. In *Energy Technology Perspectives 2008*, CSP would save annually about 1 260 Mt CO_2 in the BLUE scenario – 7% of a total 18 Gt CO_2 avoided in electricity production relative to the reference scenario. Other polluting emissions – from SO_x to NO_x, metals and particulate matters – would also be avoided.

Local impacts

An 80 MW trough plant requires about 1.2 million cubic meters of water per year, mostly for cooling the steam cycle, and for cleaning the mirrors. Dry air cooling systems could considerably reduce the consumption of water, at a cost.

The use of molten salts and synthetic oil in a CSP plant bears some risk of spillage or fire. This may in turn hinder acceptance of a project by the local population.

Technology status and development

There are four main technologies, shown in Figure 5. Troughs and Fresnel reflectors track the sun on one axis, while dishes and towers track the sun on two axes.

Troughs or parabolic cylinders concentrate the solar rays on long heat collector pipes (moving with the troughs). Current plants use some synthetic oil as heat transfer fluid. Alternative concepts include direct steam generation, and the use of molten salts as transfer fluid.

Troughs represent the most mature technology and the bulk of current projects; some have significant storage capacities. Their solar to electricity conversion can reach than 15% (annual mean value).

Linear Fresnel reflectors (LFR) use slightly curved mirrors reflecting the solar rays on a long, fixed receiver. Investment costs per mirror area are lower but the annual efficiency remains below 10%. Saturated steam is directly generated in the receiver tubes.

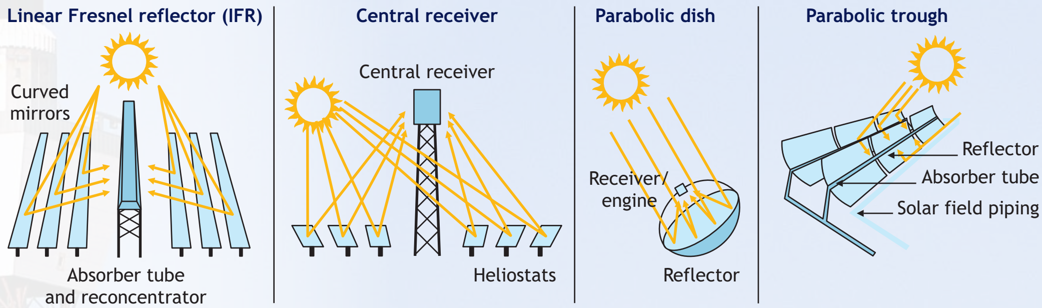
1. *External Costs from Emerging Electricity Generation Technologies*, NEEDS, 2009.

Towers or central receiver systems (CRS), concentrate the sunrays on top of a fixed tower. This allows for higher temperatures and efficiencies than linear systems. Towers can generate saturated or superheated steam directly, or use molten salts, air or other media as heat transfer fluids. Solar fields of thousands of small heliostats are proposed as a cheap alternative to state-of-the-art field design.

Parabolic dishes concentrate the sunrays on a focal point that is moving together with the dish tracking the sun, offering the highest optical efficiency on much smaller capacities (typically tens of kW). Mass production may allow them to compete with the larger systems, which benefit from economies of scale. Dish systems are less compatible with thermal storage than other CSP technologies, but require no cooling water.

Figure 5: Troughs, towers, LFR and dishes

Source: CSP Global Outlook 2009.



Storage and integration

Trough plants, linear Fresnel reflectors and most tower designs can be completed with heat storage and/or fuel back-up. The current reference technology for storage is based on molten salts.

"Integrated Solar Combined Cycle" power plants are relatively small solar fields in large combined cycle gas-fired plants. The heat from the solar field increases the production of the bottom steam cycle.

R&D priorities

Research and development efforts so far, most of them taking place within the IEA Solar PACES Implement Agreement, have been supported in particular by Germany, the European Commission and the US Department of Energy.

Improvements can be expected on all components of CSP plants. One possible step improvement with troughs would be direct steam generation, increasing the overall efficiency. Phase-change materials and concrete offer novel options for storage.

Towers have even greater room for improvements. Many innovative designs are currently proposed, with one or several towers sharing fields of heliostats, a great variety of central receiver designs, heat fluids and storage options.

Towers with air receivers feeding the gas turbine of a combined cycle power plant could offer record solar-to-electricity efficiency of around 35%.

Other possible applications are industrial process heat and brine water desalination. The production of solar fuels such as hydrogen and other energy carriers can take several roads, notably in conjunction with fossil fuels but reducing their carbon footprint (see Figure 6); it still requires significant R&D efforts.

Figure 6: Different ways of producing hydrogen from solar energy

Source: Steinfeld, 2005.