IASS FACT SHEET 2/2016
Institute for Advanced Sustainability Studies (IASS)
Potsdam, December 2016

Concentrated Solar Power

Mohammed Qader, Stefan Stückrad

The global demand for energy is growing. The International Energy Agency (IEA) projects that by 2035 world energy consumption will increase by 36 % even if countries successfully implement their plans to transform energy systems and reduce greenhouse gas emissions. This will place enormous pressure on already strained energy systems. It is crucial that we find new and sustainable energy sources to help meet future demand, diversify the energy mix, and provide climate-friendly electricity. Concentrated solar power technologies enable us to harness the infinite power of the sun to produce clean energy on a large scale.

Source: istockphoto/peterscode

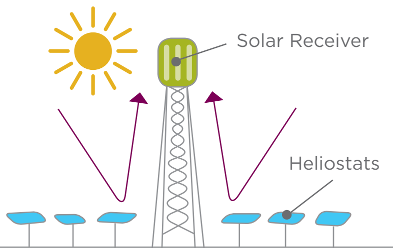
What is concentrated solar power?

Concentrated solar power (CSP) plants use mirrors or lenses to collect and concentrate solar thermal energy to generate electricity through the operation of a conventional steam turbine or heat engine. The thermal energy produced by concentrated solar power plants can be stored to generate electricity whenever it is needed, day or night. The ability to integrate thermal energy storage is one of the key advantages of concentrated solar power technologies.

What are the main technologies?

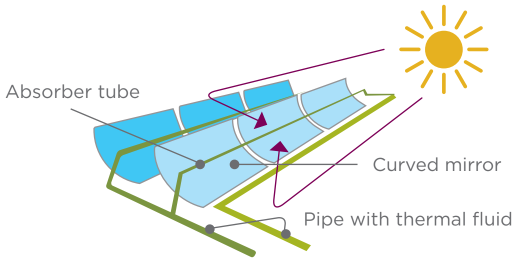
Four different technologies exist: solar towers, dish engines, parabolic troughs, and linear Fresnel collectors. Depending on the applied technology, systems for electricity generation produce temperatures of 300°–1000 °C. There are currently 5013 megawatts of installed concentrated solar power capacity worldwide, generated using parabolic troughs (83%), solar towers (13%), linear Fresnel reflectors (3.4%) and single dish engines (0.02%).[1]

Solar towers



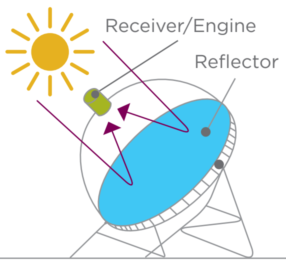
Computer-controlled flat mirrors known as heliostats track and concentrate the sunlight onto a receiver positioned at the top of a tower. The receiver, which contains a working fluid, acts as a heat exchanger and is used to boil water in a conventional steam-turbine generator to produce electricity.

Parabolic troughs



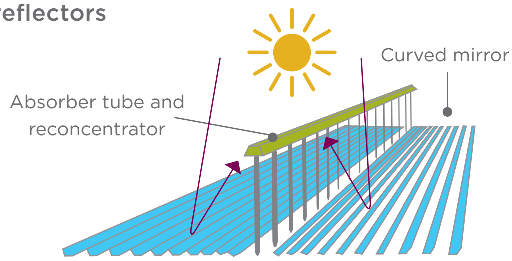
This technology uses an assembly of parabolic mirrors to concentrate sunlight onto a focal line receiver facing the mirrors. In parabolic troughs for electricity generation, this is a tube containing a heat transfer fluid such as synthetic oil, which is used to heat steam in a turbine generator to generate electricity.

Dish engines



Here, a parabolic dish of mirrors is used to reflect and concentrate sunlight onto a power conversion unit mounted at the focal point of the dish, containing a thermal receiver and, typically, a generator unit. Dish engines are suitable for modular deployment, making them ideal for remote, off-grid locations.

Linear Fresnel reflectors



Similar to parabolic trough collectors, linear Fresnel reflectors use long strips of mirrors installed next to each other at different angles to reflect sunlight onto an absorber located at the focal line of the mirrors. The absorber contains a heat transfer fluid that is passed through a heat exchanger to power a generator.

Figure 1: Concentrated Solar Power Technologies.

Source: IASS; based on Deutsches Zentrum für Luft- und Raumfahrt (DLR)

How do the technologies differ?

Concentrated solar power technologies fall into one of two categories: point concentration systems and linear concentration systems. Point concentration systems are able to achieve higher temperatures than linear concentrator systems as they focus a large number of mirrors on a single point simultaneously. The complexity of these systems makes their construction costlier, however. Linear concentrator systems, on the other hand, are more affordable to build and maintain due to their relative simplicity and use of commonly available materials.

How is the thermal energy stored?

The energy produced by concentrated solar power plants can be stored for up to sixteen hours in a thermal storage tank using a heat capture medium such as the heat transfer fluid, or a separate storage fluid or solid medium. Many systems use hot molten salt to store thermal energy. Heat can be diverted to molten salt storage whenever the system's thermal energy output exceeds the amount necessary to power the electricity generator and subsequently retrieved as required. The capacity to store thermal energy enables concentrated solar power plants to overcome the intermittency of solar energy technologies, making them viable for utility-scale operation.

Are the technologies economically feasible?

Concentrated solar power plants do not require fuel inputs to generate electricity, and the main economic parameter for their development is the initial capital cost (materials and labour). These costs vary depending on the chosen location, available solar resources, choice of technology, capacity, and other factors.

An important metric for assessing the economic feasibility of concentrated solar power (and other renewable energy) projects is the Levelised Cost of Energy (LCOE), which represents the per kilowatt-hour cost of building and operating a generating plant over an assumed financial life and activity level. This calculation includes all of the system's expected lifetime costs, including construction, financing, labour, maintenance, taxes, insurance and more.[2] As a measure of power sources, the LCOE facilitates the comparison of different methods of electricity generation.

At present the levelised cost of electricity from concentrated solar power plants frequently exceeds that of other renewable energy sources such as wind power and photovoltaics as well as conventional fossil-fuel plants. This is largely due to the relative immaturity of concentrated solar power technologies, the deployment of which is still in its early stages, with just 5 gigawatts capacity installed worldwide, compared to 432 gigawatts of installed wind power and 222 gigawatts of installed photovoltaic capacity.[3] Experts predict that the cost of concentrated solar power technologies will decrease in the coming years as breakthroughs are made in materials development and the design and manufacturing of mirrors and receivers.

Concentration method	CSP technology	Temperatures achieved (°C)	Land use[4]	Initial costs	Installed capacity in megawatts
Point	Solar Tower	800 – 1000	8 – 12	High	658
	Dish Engine	>1000	8 – 12	Average – High	1
Line	Parabolic Trough	350 – 550	6 – 8	Average	4180
	Linear Fresnel Reflector	300 – 550	4 – 6	Low	174

Table 1: Basic characteristics of CSP technologies.[5]

Source: IASS

Which areas are suitable?

Concentrated solar power plants must be located at sites with strong and reliable solar resources to be feasible. Developers refer to the Direct Normal Irradiance (DNI) value of a location to determine its suitability. DNI is the amount of solar radiation received per unit area by a surface that is always held perpendicular to the rays that come in a straight line from the direction of the sun at its current position in the sky.[6] Concentrated solar power projects are only feasible in locations where DNI exceeds 1800 kilowatt-hours per square metre per year. Regions such as the southwestern United States, the Middle East and North Africa, South Africa, Australia, Mexico, Chile, and Southern Europe receive sufficient DNI for concentrated solar power projects.

More than 80% of the current installed capacity of concentrated solar power is located in Spain and the USA. Parabolic trough and power tower systems make up the bulk of this capacity. The Ivanpah Solar Electric Generating System in the Mojave Desert (California, USA) is the largest plant in the world. It consists of three solar thermal plants, each with its own power tower and solar field, with a gross capacity of 392 megawatts. Spain hosts forty-four operational parabolic trough plants, each with a capacity of 50 megawatts. The largest operational linear Fresnel reflector plant in the world is located in India and boasts a capacity of 125 megawatts.

What major projects are in development?

The TUNUR project in Tunisia is the largest single project currently under development, with a planned capacity of 2.25 gigawatts. The facility will comprise eighteen power towers, each with a capacity of 125 megawatts. The first of three concentrated solar power plants at Noor-Ouarzazate in Morocco, with an installed capacity of 160 megawatts, is already operational, and the three plants are expected to produce 510 megawatts by 2018. Other countries that have announced plans for concentrated solar power projects include China, Chile, and the United States, with total capacities of 1864 megawatts, 1300 megawatts, and 810 megawatts, respectively.

DISTRIBUTION OF GLOBAL SOLAR RESOURCES

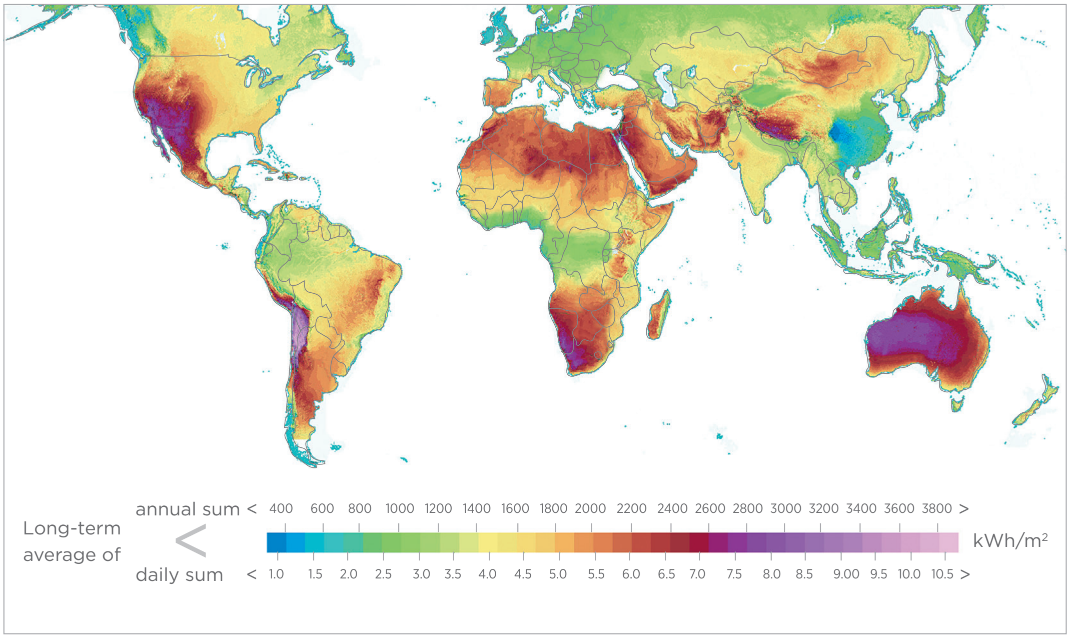


Figure 2: Global solar resources (Direct Normal Irradiation).

Source: IASS; based on DNI Solar Map 2015 Solargis

Is concentrated solar power sustainable?

Most concentrated solar power plants are located in arid regions, and the reliance of steam turbines on water resources is critical. Despite this, concentrated solar power compares favourably with other energy sources in terms of its low carbon, land- and water-use footprints. These positive environmental aspects, combined with its ability to provide a reliable and flexible power supply, suggest that concentrated solar power could play a significant role in a sustainable future electricity mix. The utility-scale deployment of these technologies will help to improve air quality and contribute to efforts to protect global climate.

THE FUTURE OF CONCENTRATED SOLAR POWER

The first commercial concentrated solar power plants were installed over thirty years ago. A range of challenges, including high capital costs, a lack of innovation and competition from the photovoltaic sector, has inhibited the growth of concentrated solar power. However experts anticipate steady growth in the years ahead, driven by ambitious renewable energy targets, falling costs, higher operating temperatures, and improved life-cycle efficiency.

The expansion of concentrated solar power into emerging economies is expected to continue, with the technology providing a means to reduce dependence on fuel imports, strengthen energy security, and deliver environmental and health benefits. The long-term prospects for concentrated solar power are promising, and according to the International Energy Agency (IEA), its share of global electricity generation could reach 11% by 2050.

[1] www.csptoday.com

[2] U.S. Energy Information Administration (2014). *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2014.* Available at: https://www.eia.gov/forecasts/aeo/pdf/electricity_generation_2014.pdf.

[3] International Renewable Energy Agency (2016). Renewable Capacity Statistics 2016. Available at: http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Capacity_Statistics_2016.pdf

[4] Square metres per megawatt-hour per year.

[5] Sources: Müller-Steinhagen, H., Trieb, F. (2004). Concentrating Solar Power – A Review of the Technology. – Ingenia, 18, pp. 43–50; Lovegrove, K., Stein, W. (2012). *Concentrating Solar Power Technology – Principles, Developments and Applications.* Woodhead Publishing, Cambridge; www.csptoday.com.

[6] Solar Electric Power Association (2014). *Predicting Solar Power Production: Irradiance Forecasting Models, Applications and Future Prospects.* Available at: http://www.sepapower.org/.

Institute for Advanced Sustainability Studies Potsdam (IASS) e. V.

Funded by the ministries of research of the Federal Republic of Germany and the State of Brandenburg, the Institute for Advanced Sustainability Studies (IASS) aims to identify and promote development pathways for a global transformation towards a sustainable society. The IASS employs a transdisciplinary approach that encourages dialogue to understand sustainability issues and generate potential solutions in cooperation with partners from the sciences, politics, the economy, and civil society. A strong network of national and international partners supports the work of the institute. Its central research topics include the energy transition, emerging technologies, climate change, air quality, systemic risks, governance and participation, and cultures of transformation.

Author contact:
Mohammed Qader: mohammed.qader@iass-potsdam.de
Stefan Stückrad: stefan.stueckrad@iass-potsdam.de

Editing:
Alexander Grieß/Damian Harrison

Address:
Berliner Strasse 130
14467 Potsdam
Germany
Phone: 0049 331-28822-340
e-mail: media@iass-potsdam.de
www.iass-potsdam.de

DOI: 10.2312/iass.2016.029

SPONSORED BY THE
Federal Ministry of Education and Research
FONA Research for Sustainable Development BMBF
LAND BRANDENBURG
Ministerium für Wissenschaft, Forschung und Kultur