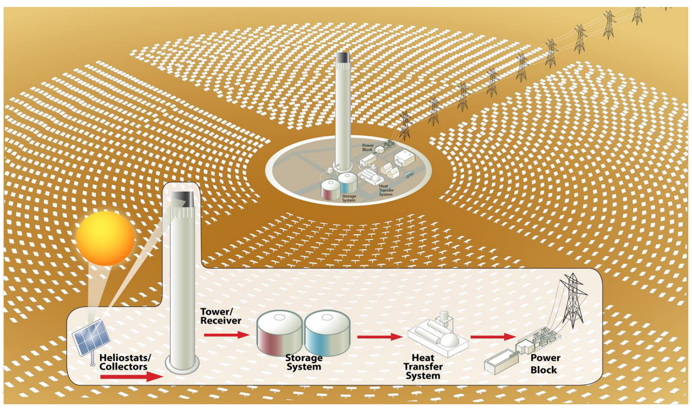
CONCENTRATING SOLAR TECHNOLOGIES FOR ENERGY DECARBONIZATION

Concentrating solar technologies can provide clean electricity, heat, and long-duration energy storage for utility-scale and industrial applications. These technologies use an array of mirrors to concentrate sunlight and heat media (e.g., molten salt, particles) to high temperatures of ~500-1000 degrees Celsius. The heated media can then be used to produce steam to generate electricity or stored for on-demand energy production. The high-temperature heat can also be used directly in industrial processes like cement production or in thermochemical synthesis of fuels and chemicals.



Schematic design of a concentrating solar plant, showing a heliostat field, receiving tower, thermal storage, heat transfer system, and power block for thermal-to-power conversion.

THE CHALLENGE

Meeting our nation's goals to reduce greenhouse gas (GHG) emissions and address climate change will require decarbonization of the entire energy sector, including electricity, transportation, and industrial processes. Through continued advancements in materials, components, and systems integration, concentrating solar technologies can be used together with other renewable and carbon-free energy technologies to meet these targets.

Concentrating solar can serve as a platform technology to address three crucial decarbonization challenges:

- Clean energy: The U.S. Department of Energy envisions decarbonizing the nation's electric grid by 2050, calling for an additional 39 GW_e of concentrating solar power (CSP) with thermal energy storage. New Mexico and several other states have similar plans to build out clean energy resources and infrastructure.
- Energy storage: Clean but intermittent renewables require safe, cost-efficient storage for widespread utility and acceptance. DOE has set a goal to reduce the levelized cost of energy (LCOE) to five cents per kWh by 2030 for long-duration stationary applications.
- Industrial emissions: According to the World Resources Institute, industry accounts for 30% of U.S. GHG emissions and is much harder to decarbonize than other sectors.

THE SANDIA APPROACH

Sandia began researching concentrating solar technologies more than 40 years ago, with construction of the National Solar Thermal Test Facility (NSTTF). The facility's primary goal is to provide experimental engineering resources for the design, construction, testing and operation of components and systems for industrial-scale concentrating solar thermal (CST) applications.

The NSTTF offers a comprehensive testing environment, from benchtop to prototype scale. At the NSTTF heliostat field, 212 computer-controlled, mirror-mounted units track the sun on two axes and reflect concentrated solar energy onto a 200-foot solar tower, producing a total thermal capacity of six MW_{th} and a peak flux of 300 W/cm^2. The solar tower features three test bays equipped with sensors, a wind tunnel, cameras, and instrumentation for customized conjugate effects testing. The NSTTF also has an electric-heating test facility with a 20kW test stand for evaluating sCO_2 heat exchangers, solar furnace, 7.2 kW_e high-flux solar simulator, molten-salt test loop, Heliostat Controls testbed, and other facilities and equipment for testing CST components and systems.

CSP FOR CLEAN ENERGY

Commercial CSP systems were first deployed in the U.S. in the 1980s. Today, CSP plants provide more than six GW_e of clean, renewable power capacity worldwide, with another three GW_e under construction or in development. All commercial CST power plants around the world use technology developed or tested at Sandia.

Next-generation CST tower systems have the potential to lower the cost of solar thermal generation by using solid particles as alternative heat transfer media to increase the CST thermal-to-electric efficiency. Currently under construction at the NSTTF, the Generation 3 Particle Pilot Plant (G3P3) will demonstrate for the first time an integrated system using particles as the heat transfer media with a two MW_{th} receiver, six hours of energy storage, a one MW particle to sCO_2 heat exchanger, and particle conveyance systems.

Next-generation CSP towers like G3P3 will operate at higher temperatures (>900 degrees Celsius) to improve efficiency and lower costs, which in turn calls for new system materials and components. Sandia provides R&D capabilities in materials science, chemistry, computational modeling, mechanical fabrication, and techno-economic analysis. From coatings to salts to valves, Sandia scientists both develop and analyze the techno-economic benefits of integrating new materials into CSP plants.

A proposed 100 MW_e CSP/photovoltaic (PV) solar/energy storage hybrid facility for joint use by Kirtland Air Force Base and Sandia illustrates the technology's potential. The facility is projected to yield 500-600 GWh of electricity each year, while reducing annual CO_2 emissions by an estimated 300,000 tons — the equivalent annual carbon emissions from about 60,000 passenger vehicles.

CST FOR ENERGY STORAGE

As renewables become a larger part of the grid, the need grows for large-capacity, longer-duration energy storage. Studies have shown that for storage longer than six hours, CST with storage costs less than PV plus battery storage.

In addition to particle CST's potential to lower costs and improve system efficiency, solid particles can help advance the duration and efficiency of thermal storage for off-sun utilization and/or electric generation. Sandia's G3P3 will use black ceramic sand-like particles to gather and store thermal energy at temperatures >700 degrees Celsius for use in a more efficient supercritical CO_2 closed-loop Brayton power cycle—even when the sun isn't shining. Analysis by Sandia researchers on higher temperature particle-based CST has shown the ability to deliver dispatchable solar thermal generation paired with 14+ hour storage at an LCOE of about six cents per kWh.

Innovations from Sandia scientists will improve the reliability and performance of particle CST systems with high-temperature mass flow sensors and a modular slide gate system for controlling particle flows, as well as other particle-specific technologies.

CSP FOR INDUSTRIAL DECARBONIZATION

In addition to supplying renewable electricity, concentrating solar technologies offer a carbon-free alternative to fossil fuels for generating industrial process heat and for thermochemical applications.

Recent research and studies have demonstrated the feasibility of using concentrating solar to produce high-temperature process heat (300-1000 degrees Celsius) for difficult to decarbonize industrial and manufacturing applications, such as cement and steel production. Sandia is currently working with collaborators to optimize heat-transfer processes and component designs for the solar-thermal production of clinker, a kiln-baked intermediary product used in cement production.

Sandia also integrates our experience with CST and materials science to advance solar thermochemical applications. Sandia researchers have demonstrated solar thermochemical hydrogen (STCH) production, the production of solar fuels for heavy transportation, solar thermochemical energy storage, and solar-thermal ammonia production (STAP). The decarbonization of transportation and agricultural sectors depends on the green production of these chemicals.

Sandia researchers have explored the use of concentrating solar thermal energy for low-carbon industrial ammonia production. Currently, conventional ammonia production accounts for roughly 1.5% of global CO_2 emissions.

CLIMATE SECURITY AT SANDIA

Concentrating solar can serve as a critical technology to address clean energy, energy storage, and industrial emissions challenges. Using capabilities from across the Labs, Sandia integrates clean energy research and development to support our missions and address the national and global security threats associated with the rapidly evolving climate crisis. Our vision is to advance climate security through science, technology, and action.

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