THE RIGHTFUL PLACE OF SCIENCE:

GOVERNMENT & ENERGY INNOVATION

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Tempe, AZ and Washington, DC

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Model citation for this volume:

Sarewitz, D., ed. 2014. *The Rightful Place of Science: Government & Energy Innovation*. Tempe, AZ: Consortium for Science, Policy & Outcomes.

The Rightful Place of Science series explores the complex interactions among science, technology, politics, and the human condition.

Other volumes in this series:

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Zachary, G. P., ed. 2013. *The Rightful Place of Science: Politics*. Tempe, AZ: Consortium for Science, Policy & Outcomes.

ISBN: 0692297502

ISBN-13: 978-0692297506

LCCN: 2014917540

FIRST EDITION, NOVEMBER 2014

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THE GOVERNMENT ROLE IN DEVELOPING SOLAR THERMAL TECHNOLOGY

Miles Brundage

Introduction

Solar thermal power, also known as concentrating solar power, is a renewable source of energy that captures solar radiation the form of heat and uses that heat to drive a turbine that generates electricity. (Solar photovoltaic cells, in contrast, directly convert sunlight to electricity). Several large-scale solar thermal power plants have been built in the United States, and more are currently under construction in the Southwestern United States, California, and in countries including Spain, Israel, South Africa, and India. Compared to solar photovoltaics, solar thermal energy has the advantage of being able to store energy for hours in the form of heat, which allows production of electricity into the night and smoothing out of fluctuations when the weather is cloudy. This storage capability, as well as the relative technical simplicity of solar thermal systems, and the availability and reasonable cost of constituent materials and components, has led to rapid

growth in the market for solar thermal power plants, and promises substantial potential for future growth.

The U.S. federal government has played a significant role in the development of solar thermal technology over the past four decades. This influence has occurred through a variety of mechanisms, including funding of basic research at universities and research and development at National Laboratories, conducting demonstration projects in partnership with industry, implementing subsidies, and developing solar radiation maps for the United States to aid industry in siting power plants.

Solar Thermal Power Fundamentals

There are four main types of solar thermal power plants, characterized by the different ways that they concentrate solar radiation before using the collected heat to generate electricity:

- Parabolic trough systems use a reflective trough to concentrate sunlight on a receiver tube running parallel to the trough.
- Linear Fresnel systems use an array of flat or slightly curved mirrors to concentrate sunlight on a downward-facing linear receiver.
- Power tower systems use an array of heliostats (tracking mirrors) to focus sunlight on a central tower where the generator is located.
- Dish-engine (or dish-Stirling) systems use a series of parabolic dishes to concentrate sunlight on an engine located directly above the dishes (rather than at a central location at the power plant, as in the other system designs).[1]

These four varieties of solar thermal power generation have different levels of technological maturity, and each has its own advantages and disadvantages in terms of

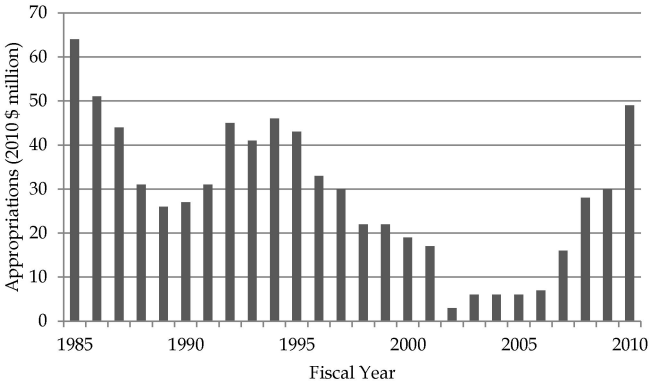
water requirements, land area requirements, and maximum operating temperature (which is correlated with the efficiency of the system).[2] Parabolic trough systems are the most mature and make up the majority of the solar thermal systems currently in operation. Linear Fresnel systems are relatively new and untested, and have primarily been developed outside the United States, but have some possible advantages such as the relative ease of manufacturing flat reflectors compared to curved ones. Power tower systems have the potential to operate at higher temperatures and efficiencies than other approaches and as such are currently receiving significant industry attention, though they still lag behind parabolic trough systems in maturity and market penetration. Finally, dish-engine systems have been proven to be feasible since the 1980s and have some advantages such as low water requirements and flexibility to work in either a distributed or utility-scale fashion (since each dish independently provides electricity rather than requiring a central generator for a whole plant, as with power tower systems). However, dish-engine systems are currently unable to store energy, though some research is being done to address this limitation.

History of Solar Thermal Technology Development

In response to oil crises of the 1970s, the U.S. federal government began investing millions of dollars annually in the development of solar thermal technology along with other renewable technologies such as photovoltaics and wind power.[3] Support for solar thermal began through the National Science Foundation with research on power towers, but since those early efforts, most federal support has come from the U.S. Department of Energy (DOE) and its network of National Laboratories.[4] In addition to research and development support, financial incentives for solar thermal power plants have played a critical

role in the commercialization of solar thermal technology, such as through tax incentives administered by the U.S. Department of the Treasury and loan guarantees from DOE.

Figure 1. DOE Funding for CSP Technologies



Source: Recreated from the U.S. Department of Energy, *Report on the First Quadrennial Technology Review: Technology Assessments* (August 2012).

The DOE has funded solar thermal research and development in industry and academia since the late 1970s and has conducted its own research through the National Laboratories. Laboratories such as Lawrence Livermore National Laboratory and Sandia National Laboratories, which have historically been focused on weapons research, have been major sites of solar thermal research over the past three decades in response to the 1970s' oil crises and the characterization of energy supply as a national security issue by national leaders beginning with President Carter. Sandia, for example, established a solar thermal testing facility in 1979 which is still used by industry partners to test new solar thermal collectors, generator, and thermal storage designs under controlled conditions. The Solar Energy Research Institute, or SERI

(later renamed the National Renewable Energy Laboratory, or NREL) has also been prominently engaged in research on both photovoltaic and solar thermal power systems, and leads the solar resource assessments which industry draws on to predict power plant output and reliability for a given geographic area.[5]

The first commercial solar thermal power plant in the United States was Solar Energy Generating Systems (SEGS), which was built in stages (SEGS I through SEGS IX) from 1983 to 1990. Located in California's Mojave Desert, SEGS remains in operation today with over 350 MW of capacity.[6] SEGS was built by Luz Industries and helped to demonstrate the feasibility and reduce the costs associated with parabolic trough solar thermal systems. Luz ultimately went bankrupt, citing fluctuation in government policies as one of the reasons for its unprofitability, but investors in particular facilities (which Luz raised capital for individually) were able to recoup their investments.[7] While the plant was built by a private company with no direct funding from DOE, Luz benefited from prior federal research in parabolic troughs and specialized coatings for pipe-receivers. Additionally, Luz was able to invest in a technology that was untested at the time partially due to government incentives, most notably a 10% investment tax credit (ITC) and a 15% energy tax credit (ETC) instituted by the Energy Tax Act of 1978, as well as a state-level tax credit. Lastly, the Public Utilities Regulatory Policy Act (PURPA) of 1978 influenced Luz's investment decisions by requiring utilities to purchase electricity from generating facilities that meet certain requirements, thus incentivizing Luz to build plants meeting these requirements.[8] As an example of the influence of this legislation, PURPA affected Luz's decisions on the sizing of individual facilities—specifically, plants were designed so as to avoid exceeding 30 MW and 80 MW cut-off levels for eligibility, so several SEGS sites have precisely those power levels. While a Luz executive later complained that

such size cut-offs were harmful by preventing more flexible engineering of the plants (solar thermal plants have different ideal sizes based on land availability, design, storage, etc.), PURPA's guarantee of a market seems to have been essential to Luz's temporary success with SEGS.

During the 1980s and 1990s, two pilot projects in power tower technology—Solar One and Solar Two—were developed by a consortium of government and industry contributors (including DOE, Southern California Edison, and the California Energy Commission), with the federal government contributing half of the cost.[9] The Solar One and Solar Two projects accelerated technical progress in understanding the challenges of operating such plants, which were considered too financially risky to be developed solely by private investors at the time.[10] Sandia National Laboratory and NREL led the design and testing of these projects. Based in part on these demonstrations that large-scale power towers were feasible, a commercial power tower plant has since been built in California and many are under construction around the world. Industry has benefited from lessons learned through the projects;[11] in particular, the Solar Two plant helped validate molten salt as a means of energy storage, which has since been adopted in other facilities.[12] A key advantage of power towers comes from the high operating temperature they produce, which leads to higher efficiency and lower thermal storage costs. Their high temperatures also make power towers suitable for incorporation in hybrid fossil fuel-solar plants, and power tower systems are scalable to a wide range of plant sizes.[13]

The federal government also played a critical role in the development of dish-engine technologies through early research in the 1970s and 1980s at NASA's Jet Propulsion Laboratory and the DOE weapons labs, and through later collaborations with industry. In the early 1990s, San-

dia National Laboratories and NREL partnered with Cummins Power Generation on a 50-50 cost-shared joint venture to develop dish-engine systems, though Cummins ultimately abandoned the technology.[14] While DOE continues to fund research on improving dish-engine technology,[15] one of the main companies working on such technologies, Stirling Energy Systems, filed for bankruptcy in 2011, and the future of the technology is unclear, with only one operating facility at present and one under construction.[16]

The federal government has provided various financial incentives to energy producers over the last several decades, including some that benefitted solar thermal technology. As noted earlier, construction of the first (and to this day, still the largest) solar thermal plant, SEGS, was incentivized through federal tax credits instituted in 1978, but fluctuation and uncertainty in these incentives created difficulties for making long-term investments.[17] Historically, tax credits for renewable energy in the United States have been extended near the time of their expiration, but some lapses have occurred, and lack of long-term predictability may deter corporate commitments to these technologies. Currently, the relevant investment tax credit for solar is set to last through 2016.[18] Other financial incentives such as accelerated depreciation of capital through the Modified Accelerated Cost Recovery System (MARCS), established in 1986, have also benefited the solar thermal industry.[19]

The American Recovery and Reinvestment Act of 2009 (the "Recovery Act" for short, also known as the stimulus package) invested billions of dollars in scaling up solar energy production, including solar thermal, through direct grants as well as loan guarantees. This has led to several large-scale solar thermal projects that are currently under construction or in operation, including some of the largest solar thermal plants ever built.[20] The DOE Loan

Guarantee Program has supported projects such as Abengoa's 280 MW parabolic trough plant near Gila Bend, Arizona; NextEra Energy Resource's 250 MW parabolic trough plant in Riverside, California; and NRG Energy and Brightsource Energy's 377 MW power tower project in Ivanpah, California (note that Brightsource Energy was founded by many of the executives involved in Luz's construction of SEGS, discussed earlier).[21] The Treasury Department's 1603 Grant Program, which has since been allowed to expire, gave grants to companies in lieu of tax credits and supported the one operating dish-engine system, in Peoria, Arizona.[22] Of these, the Solana plant by Abengoa in Gila Bend, Arizona, has received particular attention both as the first commercial scale plant with molten salt storage (a technology which was demonstrated by the DOE in the 1990s) and as the biggest parabolic trough plant in the world.

Another recent development in the federal government's involvement in solar thermal technology is the launch of DOE's SunShot Initiative, which is focused on reducing the cost of solar energy (solar thermal and photovoltaic) substantially by the end of the decade to make it cost-competitive with fossil-fuel energy plants without the need for subsidies. The SunShot Initiative's "Vision Study" concluded that a combination of evolutionary and revolutionary improvements to solar photovoltaic and solar thermal technologies will be needed to bring their costs down to the agency's targets.[23] SunShot has recently funded a portfolio of research projects in academia, industry, and National Laboratories aimed at goals such as increasing system efficiency through higher temperature operations, reducing optical and thermal efficiency losses, and reducing the overall costs of building solar plants, including efforts aimed at reducing the "soft costs" (such as land acquisition and preparation, construction labor, and maintenance) of both solar photovoltaic and solar thermal technologies.[24]

Status and Prospects for Solar Thermal

Solar thermal power has advanced greatly over the past few decades, with notable improvements supported by DOE including the validation of power tower systems, improvements to the efficiency of dish-engine systems, and demonstration of feasible means of energy storage, which is critical in enabling solar thermal to compete directly with fossil fuel sources of electricity in the utility-scale power generation market and improving the economics of large-scale plants. The SunShot Vision Study outlining DOE's view of the possible future of solar technologies identifies many opportunities for further cost reduction which, if achieved, potentially allow solar power (both solar thermal and photovoltaics) to provide more than ten percent of U.S. electricity demand by 2030 and more than a quarter by 2050.[25] While past projections of the growth of solar energy production have typically been over-optimistic, the industry has, indeed, grown substantially in the U.S. in the last few years, in part due to Recovery Act funding, with installed capacity more than doubling since 2008—moreover, dozens of plants are currently under construction or recently announced worldwide, with 410 MW of solar thermal capacity installed in 2013 alone.[26]

Several factors place practical constraints on the current and future growth of solar thermal technology in the United States, including: water requirements (depending on the specific technology used); the need for financing for first-of-a-kind technologies such as new power tower, Fresnel lens, and dish-engine systems; legal and logistical issues involved in obtaining and preparing land for development; and the fact that the highest quality solar resources are generally in areas that are sparsely populated, so transmission and distribution infrastructure for the produced electricity must also be developed. On the other hand, solar thermal technologies have potential economic

advantages in that the supply chain is largely domestic (unlike, for example, photovoltaics, where much technical and production capacity lies overseas) because solar thermal systems use many components that are commonly used in other technologies. Energy storage continues to differentiate solar thermal from photovoltaic (though photovoltaic has other advantages, including no water requirement during operation and more flexibility in terms of plant size), and molten salt storage is now well-established and can greatly improve both generating capacity and overall project economics associated with utility-scale solar thermal plants. To continue to leverage these potential advantages, DOE's SunShot Initiative is currently investing tens of millions of dollars per year in research to further reduce the cost of the solar thermal technology.

Lessons for Technology Policy

Several lessons emerge from examining the history of U.S. involvement in solar thermal technology. First, stability of incentives and research and development efforts over time is critical for technology development. DOE's level of support for renewable energy research and technology innovation has fluctuated wildly since the late 1970s, which has had both direct and indirect negative effects on technology development. Solar thermal has gone through periods of boom and bust, driven in part by the availability or scarcity of government incentives, and uncertainty about the future of tax incentives. Such fluctuations negatively impacted the development of the technology both by creating market uncertainty and by dampening morale in DOE and making it difficult to attract talented program managers.[27] Another key lesson is the crucial role of government in supporting a diversity of early-stage technical approaches to a given problem. The four solar thermal technologies discussed here have all been supported to varying extents by the U.S. federal gov-

ernment, since each had (and still has) both significant uncertainties, and potential benefits, in terms of future performance and costs. Had power tower research been abandoned due to the predominance of parabolic trough systems in the market, then the renaissance in that technology today, with plants such as that at Ivanpah set to generate hundreds of megawatts of power, might not have occurred. At the same time, technologies supported by the government such as dish-engine systems have not always caught on as hoped, and it is unclear to what extent that research will ever pay off in a major way. Yet innovation paths are often highly uncertain, especially in the early stages of a technology's evolution, and a crucial government function can be to help keep a variety of technological alternatives open as markets explore the benefits of competing pathways. To this day, the future mix of power tower versus parabolic trough and other types of solar thermal plants is unclear, and the DOE remains engaged in all these areas. In the case of solar thermal, the federal government has used an array of tools, often in close partnership with the private sector, ranging from university-based R&D, to technology demonstration projects, to various investment incentives, aimed at improving the technological base, and the capacity for learning in the private sector.

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