

Juice from Concentrate

Reducing Emissions with Concentrating Solar Thermal Power

Britt Childs Staley

Jenna Goodward

Clayton Rigdon

Andrew MacBride

in conjunction with...

WORLD RESOURCES INSTITUTE

Goldman Sachs Center for Environmental Markets

Deploying Climate-Friendly Technologies: A Wedges Approach to Clean Investment

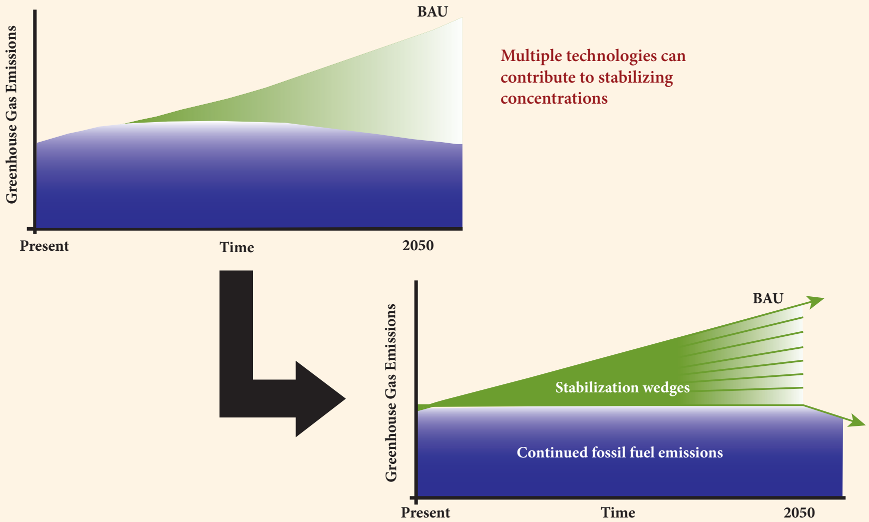
There is no shortage of options for addressing global climate change. The more difficult task is determining which solution, or mix of solutions, will reduce greenhouse gas (GHG) emissions at the scale needed to avoid disastrous climate change impacts.

In the face of rapid economic and population growth and rising energy demand, it is clear that technology must be part of the solution. We will need significantly cleaner energy sources than the ones used today, and much faster market penetration than has been the historic norm.

In a 2004 Science magazine article, Princeton professors Rob Socolow and Stephen Pacala introduced the "wedges" approach to frame this debate. The idea is elegant and simple. To stabilize GHG emissions in the next 50 years, the world must reduce emissions by about 7 gigatons of carbon (not carbon dioxide) compared to "business as usual" scenarios. So Socolow and Pacala identified 15 stabilization wedges that, if deployed at a significant global scale, could reduce emissions by 1 gigaton each. At 1 gigaton apiece, each technology wedge still represents a huge investment, but each wedge is nonetheless conceivable.

Seven gigatons of reductions are needed to achieve stabilization, so 7 of 15 wedges would, in theory, reach that goal. If deeper reductions became necessary, additional wedges could be added to the mix.

The Wedges Concept



Source: Pacalo & Socolow. Science, 2004. Each "wedge" in this figure represents 1 gigaton of carbon per year; seven wedges are needed if emissions are to be brought back to current levels by 2050 globally - and because of the likely increase in demand, additional efforts would be needed post-2050 to stabilize concentrations. Pacala and Socolow identify options for 15 wedges in their analysis.

The challenge for policymakers is deciding which wedges are preferable, and determining how to redirect capital toward deployment of preferred technologies. WRI's climate policy and capital markets projects have teamed up to analyze the best ways to accelerate global adoption of technologies in the wedges model through government policies, corporate action, and financial investment. In other words, to turn the wedges approach into action as quickly as possible.

Juice from Concentrate

Reducing Emissions with Concentrating Solar Thermal Power

Britt Childs Staley

Jenna Goodward

Clayton Rigdon

Andrew MacBride

in conjunction with...

WORLD RESOURCES INSTITUTE

Goldman Sachs Center for Environmental Markets

Acknowledgments

The authors gratefully acknowledge the help and guidance of their WRI colleagues throughout the production of this report, particularly Andrew Aulisi, Rob Bradley, Jonathan Pershing, and Janet Ranganathan. The authors also wish to thank all those whom we consulted in our research and who informed our evolving analysis. They are too many to list here, but their input was invaluable.

This report benefited enormously from a thorough peer-review process. We would like to thank our colleagues John Larsen, Smita Nakhooda, Alex Perera, and Allison Sobel for their input. As well, the thoughtful comments and suggestions of Tim Duane, Bruce Kelly, Alan Miller, Terry Murphy, Cédric Philibert, and Tracy Wolstencroft and Nushin Kormi and their colleagues at Goldman Sachs greatly improved this manuscript. Any remaining errors and omissions are, of course, the responsibility of the authors.

For editing, design, and production support, we thank Hyacinth Billings, Jennie Hommel, Casey Freeman, Greg Fuhs, and Karen Holmes.

Finally, this report would not have been possible without the generous financial support of the Goldman Sachs Center for Environmental Markets.

Hyacinth Billings
Publications Director

Britt Childs Staley, Jenna Goodward, Clayton Rigdon, Andrew MacBride
Authors

ISBN: 978-1-56973-725-5

Table of Contents

Figures and Tables

FIGURES

TABLES

BOXES

List of Acronyms

AC	Alternating Current
AEP	American Electric Power
AZNM	Arizona-New Mexico-S. Nevada NERC Sub-region
BAP	Bali Action Plan
BAU	Business-as-usual
CAMX	California-Mexico NERC Sub-region
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CER	Certified Emissions Reduction
CLFR	Compact Linear Fresnel Reflectors
CPUC	California Public Utilities Commission
CST	Concentrated Solar Thermal
DC	Direct Current
DLR	German Aerospace Center
DNI	Direct Normal Irradiance
DOE	United States Department of Energy
eGRID	Emissions and Generation Resource Integrated Database
EIA	Energy Information Administration
EPC	Engineering, Procurement and Construction Firm
ETS	Emissions Trading Scheme
EU	European Union
FIT	Feed-In Tariff
GEF	Global Environment Facility
GHG	Greenhouse Gas
GW	Gigawatt
HTF	Heat Transfer Fluid
HVDC	High Voltage Direct Current
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPP	Independent Power Producer
ISCC	Integrated Solar Combined-Cycle
ITC	Investment Tax Credit
KfW	KfW Bankengruppe (German Development Bank)
kV	Kilovolt
kWh	Kilowatt-hour
LCOE	Levelized Cost of Electricity
MENA	Middle East and North Africa
MPR	Market Price Referent
MW	Megawatt
MWh	Megawatt-hour
NERC	North American Electric Reliability Corporation
NGCC	Combined-Cycle Natural Gas Turbine
NREL	National Renewable Energy Laboratory
O&M	Operations and Maintenance
OECD	Organisation for Economic Cooperation and Development
PC	Pulverized Coal
PPA	Power Purchase Agreement
PTC	Production Tax Credit
PV	Photovoltaic Solar Power
R&D	Research and Development
RD&D	Research, Development, and Demonstration
RE	Renewable Energy
REC	Renewable Energy Credit
RfP	Request for Proposal
RMPA	Rocky Mountain Power Area NERC Sub-region
ROE	Return on Equity
RPS	Renewable Portfolio Standard
SAM	Solar Advisor Model
SEGS	Solar Energy Generating Systems
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey

Foreword

Climate change has become an increasingly urgent global issue. Recent studies suggest that the consequences could be more severe and materialize more quickly than previously anticipated, increasing the likelihood of catastrophic damage across the world. Given the complexity, scale, and urgency of the changes needed to significantly reduce our greenhouse gas emissions, it is clear that we must use all the tools at our disposal.

The breadth and complexity of the challenge require action across a variety of economic sectors and geographies. Emissions of greenhouse gases can be reduced through energy efficiency measures, fuel switching, and meeting our energy needs through various renewable energy and low-carbon technologies. However, the overall feasibility of each option varies depending on technological readiness, government support, ability to attract finance, and scalability.

To date, the private sector has played a leading role in clean technology development and deployment. However, in order to develop the suite of technologies required to avert a dangerous climate scenario, both domestic and internationally coordinated government action is also required. If timed appropriately with technology development, government programs - including renewable portfolio standards, investment tax credits, production tax credits, and loan guarantees - can considerably spur investment activity. In addition, government support of transmission infrastructure development – whether through expediting permitting processes, addressing jurisdictional challenges, or working through trans-state challenges – can help bring renewable power generation to market at meaningful scale.

The World Resources Institute (WRI) and the Goldman Sachs Center for Environmental Markets maintain a long-standing partnership that has produced research to inform decision-making around significant environmental topics including climate change. Exploring the feasibility of new technologies and the associated policy and investment necessities is an important aspect of our collaboration. In "Juice from Concentrate", WRI examines a renewable energy resource, Concentrating Solar Thermal power (CST), that presents policy-makers and investors with a significant potential for reducing carbon dioxide emissions from coal-fired power plants. CST is a technology that uses reflective material to concentrate the sun's rays to power steam turbine or engines. By incorporating thermal energy storage, it addresses the intermittency of available sunlight and is thus a very attractive technology for utilities needing reliable power supplies. Its implementation, particularly in developing countries like China and India, could have a significant impact on global emissions reductions while meeting growing energy demand.

Finding scalable solutions to move toward a low-carbon economy is challenging. Attractive returns on investment, consistent government support, international implementation, and technological advancement are all required to scale up clean energy technologies, and CST is no exception. CST is an attractive possibility among the many technology solutions that will be needed. Its adoption is likely, but given current financing markets, policy uncertainties, and lack of clarity around the price of carbon, the scale and timing of that adoption is difficult to predict. Coordinated action among clean technology providers, investors, and policy-makers is needed to spur development of a low-carbon economy where renewable energy technologies like CST can be integrated into modern and nimble power transmission systems.

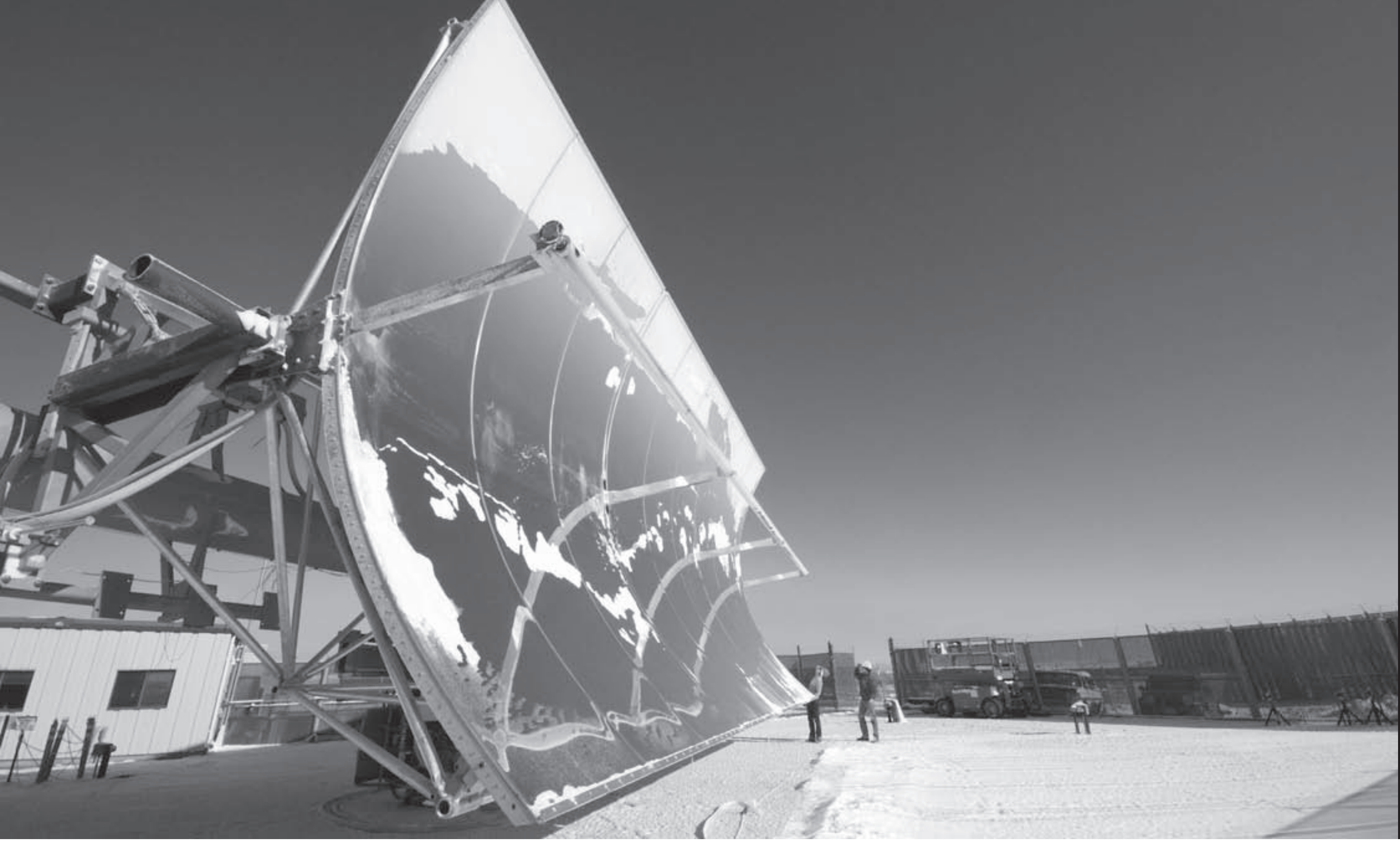
Given the urgency and severity of the climate change problem, and the challenges facing large-scale deployment of such technologies as carbon capture and storage and nuclear power, renewables - including CST – must be part of the solution. Based on the findings in the report, we look forward to engaging in discussion – and meaningful action – with our clients and partners on how to make this technology, and others, a significant part of our future power generation.

Jonathan Lash

President
World Resources Institute

Tracy Wolstencroft

Managing Director
Global Head, Center for Environmental Markets
Goldman, Sachs & Co.



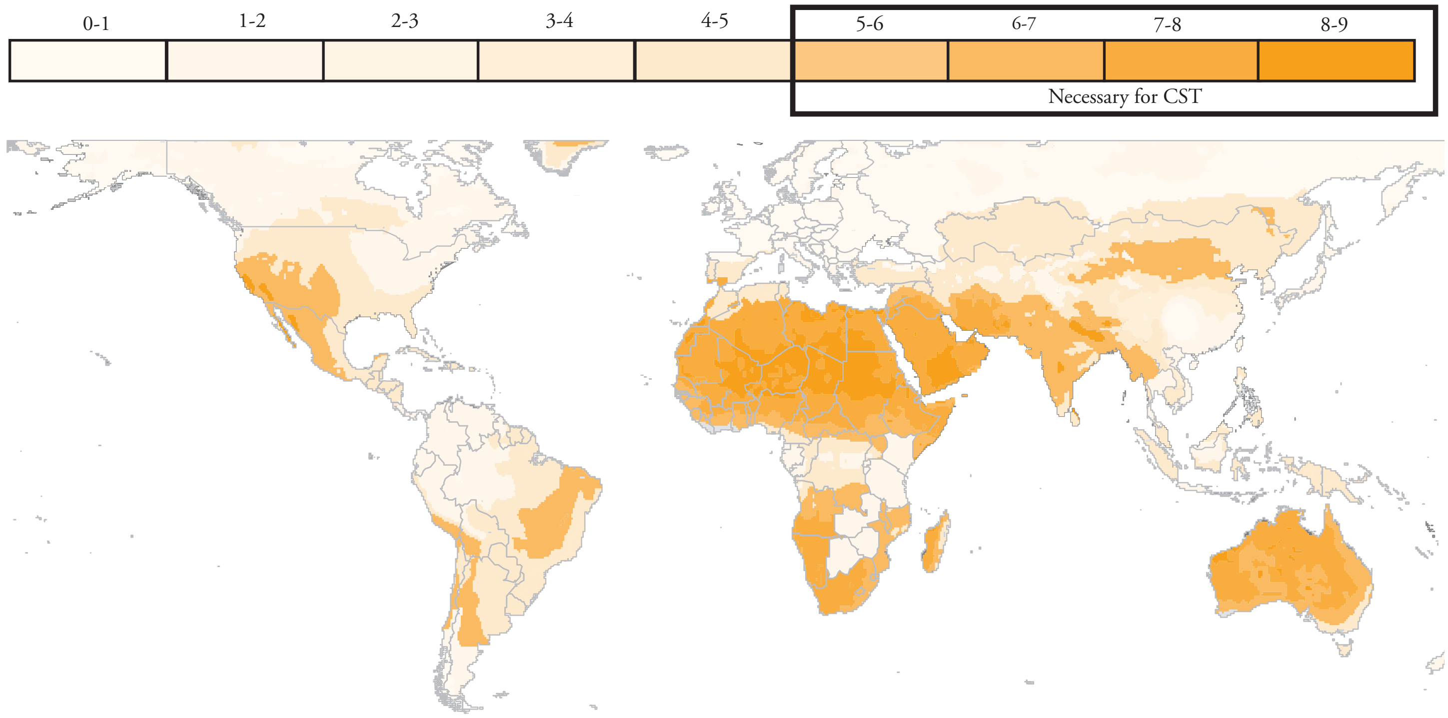
Executive Summary

In a world of rising energy prices, security concerns, and climate change, the production of energy will need to change in fundamental ways. In the electricity sector, certain renewable energy sources appear ready for the mainstream, offering not just a solution to these challenges but an exciting opportunity for investment, innovation, and job creation. Many regions are deploying wind and solar energy, successfully managing their intermittency. However, these resources are innately less predictable than coal, which limits their use at high rates of market penetration and as reliable sources of power around the clock (i.e., baseload electricity). Both developed and emerging economies require reliable power supplies on demand, and many energy analysts routinely assert that there is no realistic alternative to building more coal-fired power generators.

A serious energy alternative

This report provides a rebuttal to that assertion, outlining the potential groundbreaking role of concentrating solar thermal power (CST) in providing power on the margin of the demand curve, as well as replacing coal at the core of the power mix. If catastrophic climate change is to be averted, then reducing carbon dioxide (CO_2) emissions from fossil fuel combustion is critical, and displacing coal-fired generation is the preeminent challenge. Given the hurdles facing fast, large-scale deployment of other climate-friendly technologies such as carbon capture and storage (CCS) and nuclear power, large-scale uptake of renewable energy sources such as CST will be critical to the solution.

FIGURE 1. **Global Direct Normal Solar Radiation (kW/m²/day)**



Source: World Bank

What is concentrating thermal power?

CST uses reflective material to concentrate the sun's rays to power steam turbines or engines. When combined with thermal storage—which enables a plant to produce power under cloud cover and after the sun has set—CST can generate electricity on demand, not just when the sun is shining. Globally, solar resources are abundant. Solar resources in Australia, Mexico, the Middle East, and southern and northern Africa are equally promising. Parts of Latin America, India, central Asia, and China also have great potential (see Figure 1). Other areas, such as Europe, have solar resources that are only marginally suitable for CST, particularly in Spain and Portugal.

Because CST technology components are produced from readily available commodities such as steel and glass, bottlenecks to CST market growth will likely be no more problematic than other energy options.

Although CST is only one part of the energy solution, it potentially offers a major supply option in some of the world's largest economies and load centers.

Sun blocks

Despite the technical viability of CST, there are significant barriers of which policy-makers and investors need to be aware.

- Costs are currently high relative to coal. Further improvements to the technology will help bring costs down, and investors and operators are still learning how to design and operate plants most efficiently. The U.S. Department of Energy (DOE) has a goal of producing baseload power from CST at competitive prices by 2020. For the time being, consistent policy support will be important to accelerate deployment and market acceptance.
- The regions with the best solar resources are often arid or water-scarce. Incorporating advanced technologies such as dry cooling and wet/dry hybrid cooling systems can reduce water consumption but also increase project costs. Producing zero-carbon electricity and heat for seawater desalination is an expensive option, but may be attractive in these regions as water scarcity concerns increasingly factor into decision-making.

TABLE 1. Summary of CST Development to 2008

Technology	In Service Capacity (MW)	Planned Capacity (MW)	Total (MW)	Leading locations (including planned installations)	Companies
Trough	395	4,967	**5,362**	U.S., Spain, China, Israel, Australia, Morocco, Greece, UAE, Algeria, India, Mexico, Iran	Acciona, Iberdrola, Luz (Solel), SkyFuel, Solar Millenium, Solucar
CLFR	1	1,489	**1,490**	U.S., Libya	Ausra, SkyFuel
Tower	11	601	**612**	Spain, U.S., South Africa, Egypt	BrightSource Energy, Sener
Total	**407**	**7,057**	**7,464**		

- The most abundant solar resources are not evenly spread globally and often do not coincide perfectly with large energy-consuming population centers. Improved transmission systems will need to keep pace with the growth of CST and other renewable energy generation technologies.
- CST has some track record, but investors are still wary of new technologies. CST is capital intensive, and at a time when financial markets are struggling, measures to increase investor confidence will be important.

A bright future

Policy-makers and investors are looking for ways to meet rising energy demand while cutting CO_2 emissions from fossil fuel use. CST offers a major opportunity to meet this challenge in a way that does not increase the long-term cost of electricity. Thanks to policy support in the U.S. and Spain, in particular, the CST industry is developing into one that can deliver at scale (see Table 1). There is real scope for policy to accelerate widespread deployment of CST in the United States and in Europe at first, but also in the Middle East and North Africa, exploiting their abundant solar resources, and in major developing economies like China and India, addressing major environmental concerns. To take advantage of its potential, policies are needed to help bring down the costs of CST plants with thermal energy storage by providing predictable price support and thereby improving investor confidence, and in the longer term to improve regulation and increase investment in transmission infrastructure. The availability of CST and other renewable power options means that expanded coal use should no longer be seen as an inevitable factor in maintaining economic growth.

Key Findings

CST provides a large-scale option to deliver a zero-carbon electricity system.

1. Concentrating solar thermal power offers real potential to reduce dependence on coal and displace emissions from the power sector globally. As countries begin limiting greenhouse gas emissions, CST is an important option, on its own and as part of a broader portfolio of renewable energy technologies.

2. Storage systems can improve the economics of CST plants and improve their value proposition to utilities. Storage provides a buffer against cloudy periods, extends generation to cover peak load, and can allow a CST plant to produce power after the sun has set, helping to meet baseload power demand.

3. CST remains more expensive than coal as a generation source, but prices are expected to decline significantly as technology learning occurs. A carbon price of approximately \$115 per ton of CO_2 would be needed for CST (trough with 6 hours of storage) to become economically competitive with coal-fired power.

4. This carbon price is higher than expected from the early stages of most cap-and-trade systems, but far lower than the carbon prices projected in some climate policy studies. The effectively limitless potential for CST acts as a ceiling for carbon prices and must be considered in relation to the significant costs of inaction—in other words, the economic damages from doing nothing to mitigate climate change.

CST costs are still high compared to coal, but are expected to decline.

5. CST has been disadvantaged by high commodity prices. CSTplants require large volumes of glass, cement, and steel. Future price trends for these commodities will have a significant impact on the cost of power and its competitiveness with coal, because CST replaces lifetime fuel payments with upfront capital in its cost structure. Equally important is innovation in the CST industry. Pilot designs include substitutable materials in key components (providing a hedge against commodity price spikes).

6. Costs are expected to decline as new capacity comes online. Key areas of cost improvement will come through research and development (R&D), particularly in improved storage materials, optical design, mirrors, heat collectors, heat fluids, and plant operation. Most plants today are smaller than optimal, in some cases because of the structure of policy support (as in Spain). Larger plants (e.g., for parabolic troughs the optimal turbine size is between 150 and 250 MW) will produce additional economies of scale. Technical challenges will likely make larger plants impractical, but clustering multiple plants in proximity could reduce some fixed costs.

Several simple policy options can accelerate CST deployment and bring down costs.

7. The regulation and pricing of carbon is a reality in many markets. Traditional fossil fuels experience new competitive challenges under these conditions, and viable zero-carbon energy options stand to win big in the market for new power generation capacity.

8. Under a carbon constraint, CST with storage will be attractive to utilities. However, continued specific renewable energy support will be necessary in the near term to drive investment, as carbon prices alone are unlikely to be sufficient in the near term to cover the cost gap between CST and coal. Neither U.S. nor EU carbon market prices is expected to exceed $100 per ton of CO_2 in the near term (although prices in this range could occur by 2030, according to some recent modeling scenarios).

9. In the near term, investment will be driven in part by policy incentives. The most generous incentives at present are provided through Spain's feed-in tariff. This model is being taken up in some developing countries and may merit consideration in the United States.

U.S. support based on tax credits for investment and/or production has proven less effective, largely because it is subject to periodic and uncertain renewal. The 2008 renewal of the U.S. Investment Tax Credit (ITC) extended the support for eight years, a much longer lifespan than previously offered. This is a step in the right direction; however, investors would benefit greatly from a more stable support regime.

10. Another modification to the ITC in the U.S. allows utilities to invest directly in owning CST generation under structured tax equity deals. Previously, CST developers had to procure power purchase agreements (PPA) and tax equity investors on their own. Given the credit crunch, this is good news for the fledgling industry because it is a fresh pool of capital, but it may mean developers will need to produce more flexible business models.

11. The ability of CST to displace baseload coal and reduce emissions will depend on deploying effective storage systems and on integrating CST into a portfolio of zero-carbon power generation options. While thermal storage systems for CST already work well, research, development, and demonstration (RD&D) support would be valuable and should be aimed at bringing down the costs for these systems.

12. While the challenges of deploying CST in industrialized countries are being addressed, new coal plants are being built at a furious pace in rapidly developing countries. According to the IEA, China doubled its coal-fired generation between 2000 and 2006, and more than 40 percent of China's expected $1.3 trillion investment in added generation capacity through 2030 will likely be coal-fired. Given the rapid growth of demand in developing countries, speeding up CST deployment in these countries by even a few years could make a huge difference to the emissions trajectory. Both China and India (but particularly India) could deploy CST technology to limit their rapidly expanding coal-building activities. New multilateral financing mechanisms such as the Clean Technology Fund managed by the World Bank should support CST deployment in these countries. As a promising option to reduce GHG emissions and improve energy security, CST should be a priority in international collaboration on research, development, and deployment issues.

13. The wider application of CST will require a stronger and more integrated transmission system. In the U.S., a greater federal role and/or improved coordination between grid operators will be needed. In the EU, robust transmission links with North Africa will be critical and are already being developed.

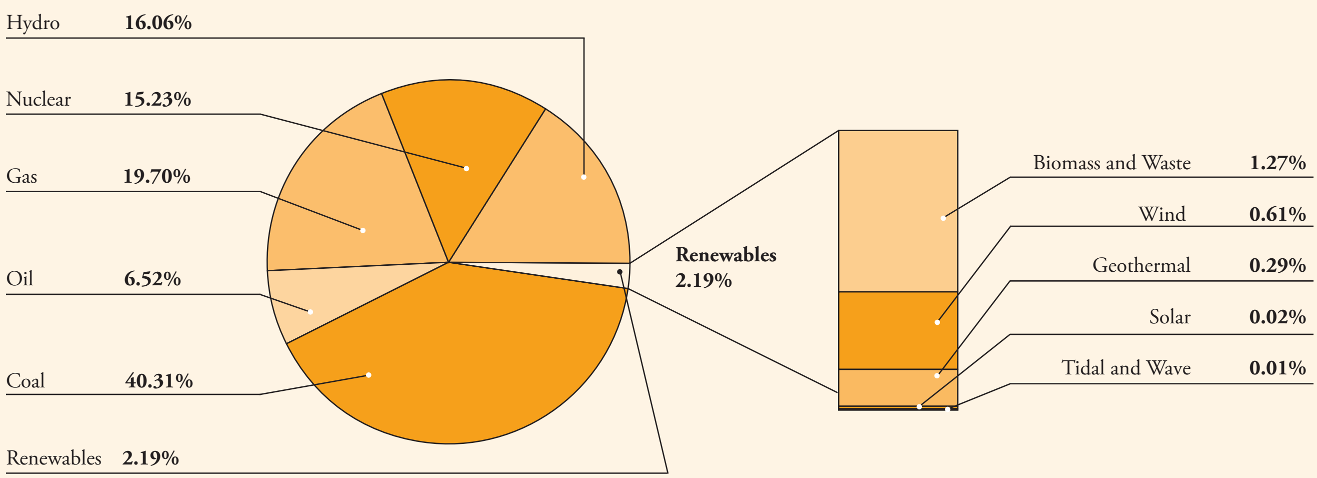
SECTION I

Introduction

The world currently faces a major energy, climate, and security crisis. Business-as-usual trends in the energy sector are completely unsustainable. Simply keeping up with increasing demand will require some $22 trillion of new energy investment over the next 25 years, according to International Energy Agency (IEA) estimates.[1] Including investments in low-carbon technologies needed to address climate change, this figure jumps to $45 trillion.[2] Reducing emissions from the power sector is particularly important to addressing climate change, as it is responsible for one-third of global greenhouse gas (GHG) emissions, and reduction in this sector will likely be more cost-effective than reductions from other key sectors such as transport and industry.[3]

To address climate change, investment must be shifted away from GHG-intensive technologies, particularly coal-fired power generation, which produces approximately 40 percent of electricity globally.[4] While gains in energy efficiency are both possible and essential, decarbonizing the power sector while satisfying growing demand for existing electricity services will require massive amounts of zero-carbon power generation. Given the challenges of large-scale deployment of carbon capture and storage (CCS) and nuclear power, large-scale uptake of renewables will clearly be necessary.[5]

FIGURE 2. **Global Electricity Generation by Fuel Type, 2005**



Source: *IEA, World Energy Outlook 2007*

Though deployment of renewables such as wind and solar technologies has increased substantially over the last decade, today renewable energy accounts for only 2 percent of worldwide electricity generation (see Figure 2). Intermittency of wind and solar energy is a significant barrier to their deployment at scale. However, concentrating solar thermal (CST) electricity,[6] which harnesses sunlight as heat to power a turbine, is a particularly promising technology for reducing GHG emissions. When combined with thermal energy storage—technologies that enable CST plants to store incoming solar radiation for later use in producing steam to power the turbines—CST offers an economical, technically feasible storage option to address the sun's intermittency, enabling more significant penetration of renewable electricity.

In this report we analyze the potential to strategically deploy CST to displace coal and to reduce global carbon dioxide (CO_2) emissions significantly. With this framing we do not intend to imply that deploying CST to displace coal is the only or best way to use the technology or that CST should be the sole source of power generation; rather, we seek to test the plausibility of replacing coal with renewables in the power sector. In the first section we discuss the technical feasibility of CST to displace coal-fired power generation.

We analyze the economic considerations of CST versus coal-fired power where solar conditions are particularly favorable. We use the U.S. electricity market as a model in many cases, but consider how lessons apply more broadly to explore the potential and barriers for displacing coal with CST globally, especially where good solar resource potential and high levels of coal use overlap. In the final section we draw lessons from experience to date with policy support for CST.

> ***"CST offers an economical, technically feasible option to address the sun's intermittency, enabling more significant penetration of renewable electricity."***

SECTION II

Uneven State of Play

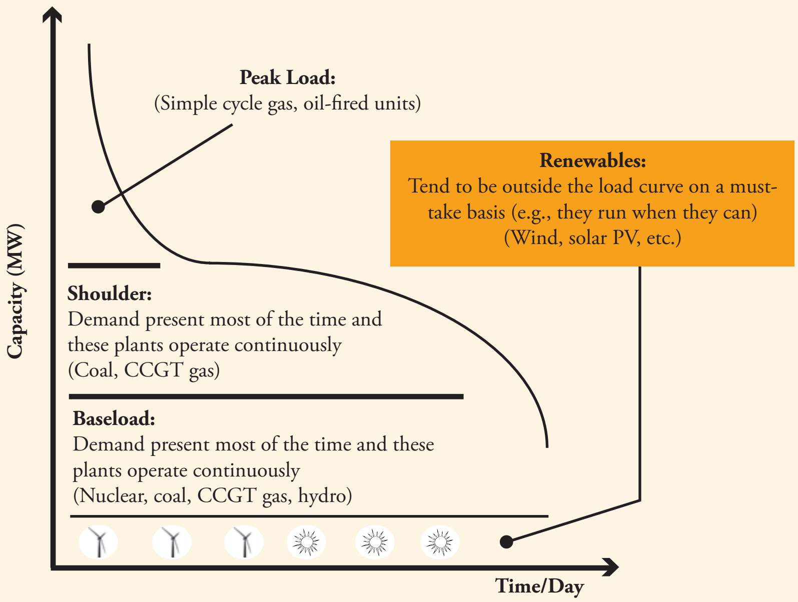
what does it take to displace coal?

Today coal power has a range of advantages over alternative technologies. First, coal plants can generate power when it is needed. Always running, they can dispatch power on demand, rather than depending on an intermittent fuel source. As a result, coal generators can operate at a high capacity factor, meaning they generate a lot of power relative to their theoretical maximum output. This feature enables them to provide steady supplies of baseload power, which is the minimum level of demand on an electricity supply system over 24 hours, or the load that exists 24 hours per day.[7] Lastly, despite major increases in the price of raw materials, coal-fired power remains relatively inexpensive.

To displace coal, alternatives should be able to match coal's ability to generate dispatchable and baseload power, and must offer that power at a competitive price. Can CST fill this role?

In this section we discuss the role of coal and CST within the broader generating mix on the grid. We introduce concentrating solar thermal technologies and discuss possible configurations, exploring the value they provide in terms of the fossil fuels they are likely to displace. Finally, we examine how CST compares to coal on key issues of cost and resources required.

FIGURE 3. **Standard U.S. Power Dispatch Curve**



Note: *This drawing is a schematic designed for illustrative purposes only.*
Source: *World Resources Institute*

> ***Adding storage or hybridization could enable CST to meet baseload power needs.***

Coal and CST on the Grid

In most places on today's grid, electricity cannot be stored economically; on an efficient grid, supply and demand are balanced in real time. Demand is not consistent; in most countries it is seasonal and varies hourly. To meet this variable demand, electricity grids rely on a mix of generating technologies with different operating characteristics (see, for instance, Figure 3). The following discussion draws primarily from the U.S. context; other electricity markets operate under different rules and regulatory structures, but the same general economic and physical principles apply.

As demand on an electricity system fluctuates throughout the day, there are periods of peak and lower demand. The term "baseload" refers to the minimum level of demand, which exists "around the clock" and throughout the year. To meet this demand, utilities rely on plants that can guarantee firm dispatch, i.e., plants that can deliver a pre-arranged amount of supply when utilities need it. This role is typically filled by coal, nuclear, and hydropower plants, which suits the interest of both the plant owners/operators and the utilities dispatching the power. These plants have high capital costs, which can only be recovered by running around the clock (see Figure 4). However, they have low operating costs—so as the cheapest generating option, they are first in the utility's dispatch order. In addition, many of these plants are not designed for start-and-stop operation, which is inefficient and can lead to accelerated wear on components and operating equipment.

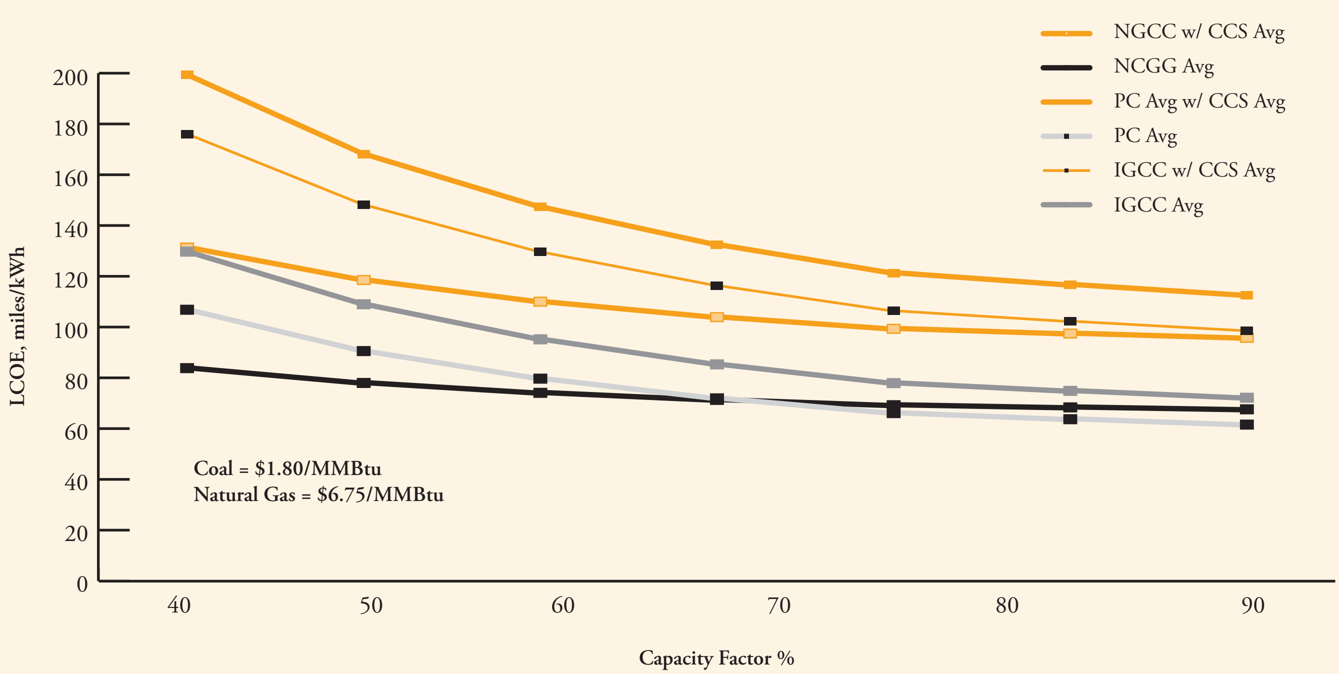
"Peaking" power sources provide supply in periods of high demand. Since they fill a smaller niche than baseload, peaking plants must be relatively inexpensive to recover their costs over a smaller lifetime output. The technologies used must be able to vary output quickly in response to fluctuating demand. Typically, peaking plants have a capacity factor of about 20 percent.[9] Simple cycle gas units, combined cycle natural gas turbines (NGCC), and oil-fired units are used as peakers to match these periods of variable demand (see Figure 4). "Shoulder" refers to generation between the lowest (i.e., baseload) and highest (i.e., peaking) demand periods. These plants have higher operating costs but lower capital costs than baseload plants, so they end up running most of the time but are turned down before baseload sources.

Dispatch order is important when analyzing the conditions necessary for CST to displace coal and eliminate even a small portion of the 7.4 billion tons of carbon dioxide released annually from global coal combustion.[10] Given the strong correlation between peak power demand and CST output, CST is currently deployed to provide shoulder and peaking power in the United States, particularly where this demand is rapidly growing. However, the GHG emissions displacement (that is, the emission reductions relative to a baseline scenario) is not as large as if CST were dispatched to displace coal-fired generation (see Box 1).

BOX 1. Emissions Reduction Potential from Displacing Fossil Fuels in the Power Sector

Renewable energy technologies can provide emissions-free electricity, but their contribution to climate stabilization depends on which fossil fuels they can displace. The emissions reduction of an installed megawatt of renewable energy is roughly twice as large if that capacity displaces coal than if it substitutes for natural gas, because of the difference in emissions intensity between the two fuels. Coal-fired power stations emit roughly 1 ton of CO_2 for every megawatt-hour (MWh) of output, while efficient natural gas plants emit about 0.5 tons of CO_2 per MWh. Thus, displacing 1 gigaton of CO_2 emissions requires displacing 28,000 MW of coal-fired power (56 average-sized coal plants) or 56,000 MW of natural gas-fired generation (approximately 280 average plants).[11] However, the first gas plants displaced will be the least efficient ones, and those with the highest rates of CO_2, SO_x, and NO_x emissions. Some low-carbon solutions may dramatically shift grid economics and grid dynamics. For instance, integrating electric or plug-in hybrid vehicles at scale could fundamentally alter the grid and dispatch by adding a significant amount of electricity storage to the grid. When charging at night, these vehicles' demand would smooth out the daily dispatch curve, increasing baseload demand; if any remained plugged in during the day, they could provide backup power that utilities could use during periods of peak demand. CST developers will need to adapt to such changing grid dynamics.

FIGURE 4. Average Levelized Cost of Electricity (Lcoe) Sensitivity to Plant Capacity

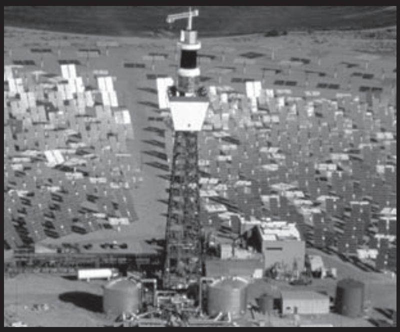


Source: *National Energy Technology Laboratory and U.S. Department of Energy*[8]

Parabolic Trough

Compact Liner Fresnel Reflector

Power Tower



Concentrating Solar Thermal: State of the Technology

Concentrating solar thermal technologies use mirrors to reflect and concentrate sunlight on a substance called a heat transfer fluid (HTF), which absorbs the heat. The hot fluid is then used to generate steam and power a steam turbine. After the fluid is cooled, it is cycled back through the solar collector field and reheated. The principal CST systems include parabolic troughs, power towers, Linear Fresnel reflectors, and dish engines. This report focuses mostly on the first three; dish engines have efficiency advantages[12] but are further from commercial availability and cost competitiveness.[13]

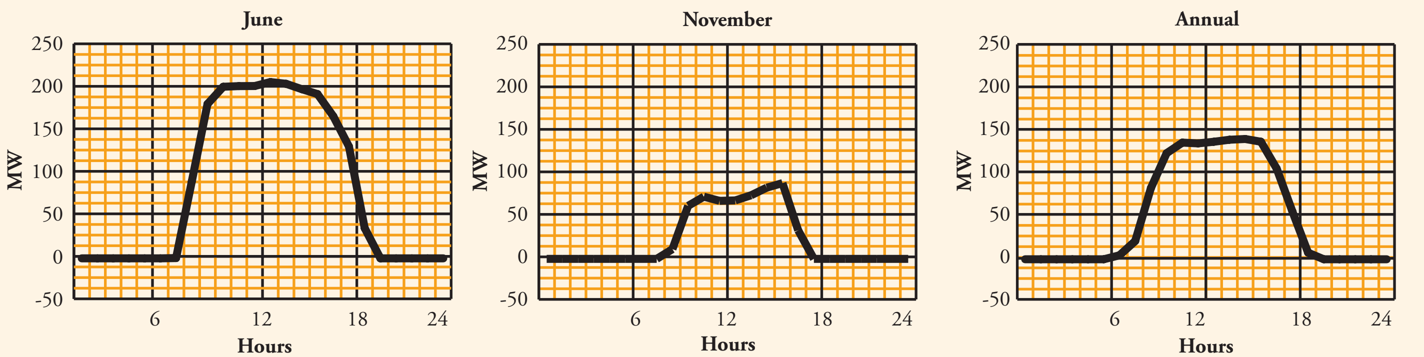
- **Parabolic Trough** concentrators use a reflective surface such as a glass mirror to reflect and focus sunlight onto a heat collection tube that runs the length of the mirrors and carries the heat transfer fluid to a turbine generator. To maintain appropriate positioning with the sun's rays, parabolic troughs "track" the sun, pivoting on a one-axis system. Troughs must be engineered to withstand bad weather, particularly wind. Parabolic troughs are the most mature of the CST technologies, with plants operating in the U.S. since the late 1980s, but the levelized cost of electricity from trough plants is still more than double that of coal-fired power.

- **Compact Linear Fresnel Reflectors** (CLFR) use flat or slightly curved mirrors to direct sunlight to an absorber positioned above the mirrors. With flat mirrors that are close to the ground, CLFRs are cheaper to produce and less vulnerable to wind damage. However, because the panels are side by side, depending on the angle of the sun one panel may obstruct or shadow another, causing CLFR systems to be less efficient compared to parabolic trough concentrators, particularly in periods of low light. Although not as technologically mature as parabolic trough technology, manufacturers of CLFRs such as Ausra and Skyfuel believe it may prove to be a lower-cost alternative.

- **Power Towers** use a large array of mirrors (heliostats) to track the sun. The sunlight is reflected from the mirrors onto a central receiver mounted on top of a tower at the center of the heliostat array. Tower technology is less mature than CLFR and trough technologies, but since the solar array focuses the sunlight onto one central receiver, power towers are capable of achieving higher temperatures than these technologies. Higher temperatures can enable towers to produce and store power at higher efficiency and lower cost than other CST technologies. Towers can use various heat transfer fluids, from water and steam to atmospheric or pressurized air, molten salts, and others.

The electrical output of a CST plant depends heavily on the quality of the solar resource, measured in Direct Normal Irradiance (DNI). DNI is the sunlight that hits perpendicular to a collector without being blocked by clouds or diffused by humidity in the air. Because it entails reflecting sunlight, CST generation can only make use of DNI, and not diffuse sunlight. As such, CST collection is limited by length of the day and intensity of instantaneous DNI. CST plants without thermal storage can have capacity factors of 20 to 30 percent in high resource areas.[14]

FIGURE 5. **Seasonal Fluctuation of CST Output (200 MW CST Plant without Storage)**



Source: *NREL Solar Advisor Model*

Firming Output: The Key to Maximizing Emissions Reductions

Without storage or fossil-powered backup, a CST plant has some reliability disadvantages similar to other renewable energy options like wind and solar photovoltaic—but not all of them. It is still easier to predict solar patterns than wind patterns, making solar more reliable, and the fact that CST plants use a thermal cycle (using heated fluid in a steam turbine) means that even without storage or backup, CST plants have a 30-minute thermal fluid buffer, avoiding an interruption in output when clouds pass over (a problem for PV). Long cloudy periods are still a problem, but with storage or hybridization (integration of fossil fuels as a backup generation source), CST can provide firm capacity.

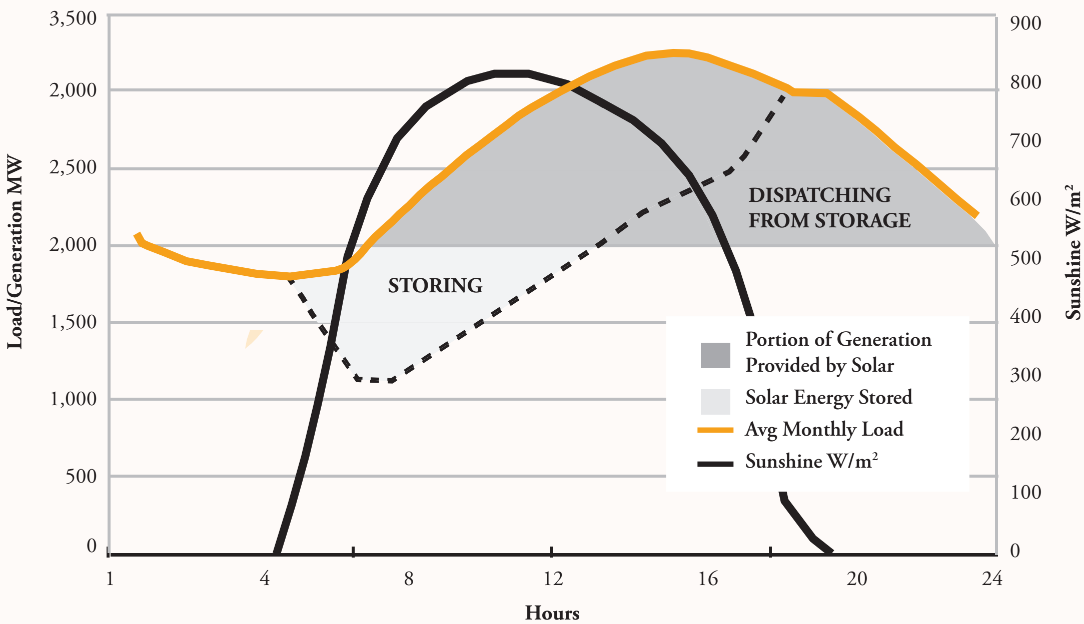
Based on current design, a trough plant with no storage can be dispatched only about 11 hours a day in summer (about 7:00 a.m. to 6:00 p.m.) and less in winter (see Figure 5). Generation may also be interrupted throughout the day due to cloud cover,[15] and is the plant's output cannot cover all of peak load, which is generally highest around 5:00 p.m., when power prices are highest and generation is most lucrative (see Figure 6).[16] As discussed above, to displace coal, CST would need to be dispatchable around the clock.[17] Adding storage or hybridization could enable CST to do this and meet baseload power needs. These options would provide a buffer against cloudy periods, extend generation to cover peak load, and enable a CST plant to generate power after sunset. Storage increases the plant's capacity factor and, if optimized for the size of the plant and resource base, may in some cases (e.g., around-the-clock production) reduce the levelized cost of electricity[18] (LCOE—the estimated lifetime costs of each system as an annualized cost per unit of electricity generation).[19]

Hybrid CST plants use a backup generation source, frequently natural gas, to supplement output during periods of low solar radiation, and thus allow for electric generation independent of solar availability. These plants have a supplementary boiler that is used to burn natural gas to create steam and power the turbine. The plants can operate using all solar input, all natural gas input, or any combination of the two, using the same steam cycle, turbines, and generators. The Solar Energy Generating Systems (SEGS) plants, the first major commercial CST deployment, were designed as hybrids and use natural gas to augment electricity production (up to 25 percent of their primary energy).

Another hybridization design option is to integrate a concentrating solar field with a natural gas combined cycle (NGCC) plant. These plant designs, called integrated solar combined cycle systems, combine steam generated from solar heat with the waste heat from a gas turbine. The National Renewable Energy Laboratory (NREL) estimates that using this configuration can approximately double steam turbine capacity; however, when the solar field is not collecting the sun's energy the steam turbine must run at a partial load.[20] This technology configuration is the choice for several projects in the U.S. as well as three projects in North Africa.

Adding storage can have the same effect as using fossil backup to firm or stabilize a CST plant's output (see Figure 6). Thermal energy is collected in the solar field when it heats a heat transfer fluid (HTF), which is typically a synthetic oil but can also be water (making steam directly) or molten salt. If not immediately used, the thermal energy in the HTF is stored, either by storing the HTF directly or by transferring its heat to another storage medium.

FIGURE 6. Concentrating Solar Thermal Plants with Storage



Source: *National Renewable Energy Laboratory, Due Diligence on Trough Technology (Price 2003)*

In the latter case, when stored energy is discharged, the heat transfer is usually reversed: heat exchanges from the storage to re-heat the HTF, which is used to make steam that powers the steam turbine. The primary storage technologies today use tanks to store heated synthetic oil or heated salt blends. For example, the Solana plant in Arizona and several parabolic trough plants in Spain are being built using synthetic oil as the HTF and molten salt as the storage medium.[21] Table 2 summarizes the current options for thermal energy storage technologies.

In general, adding storage increases a plant's capacity factor, but there will always be a seasonal disparity between summer and winter generation. For example, approximately 11-14 hours of storage will allow 24-hour generation in the summer,[22] but not in the winter.[23] However, with this level of storage, generation is quite expensive. The solar field is over-sized in the summer (that is, it receives more energy than the storage and turbine can process, and must be defocused away from the sun or turned "off"), and the additional capacity used only for generation in the winter. Towers fare somewhat better than troughs for winter generation because they can better track the sun, and thus might be more attractive to utilities with higher winter loads. For troughs, adding storage and increasing the size of the solar field can push capacity factors to about 40 percent given current plant efficiencies and proven storage materials.[24]

As the market for CST grows, so too will demand for storage technologies and use of more advanced storage methods. The market's final shape is uncertain, both in terms of supply and demand—it is not yet clear which technologies will prove most economical, nor which suppliers will survive the market's early years. Because storage is a fossil-free way to firm CST output, it is worth considering the potential implications of scaling up storage capacity for gigawatts (GW) of CST power generation capacity. Although pressure on commodity prices decreased in the wake of the global financial crisis in 2008, rapid CST industry growth (e.g., if all 9 GW of plants in the pipeline come online as planned) may create production bottlenecks. While storage tanks and heat exchangers are not highly specialized components and are widely manufactured, the special "solar salts" (nitrate, nitrite, and nitride blends) required could pose challenges to rapid scale-up. Although deposits of these salts are ample, supply chain bottlenecks, including in mining, cleaning, or manufacturing the required salt compounds could become an issue.

Storage is helpful in making the power output from a CST plant steady and reliable, and adds value by enabling plant operators to decouple the plant's generation schedule from sun and weather patterns. For a solar field of any given size, a fixed amount of solar energy is collected in a day, but that energy can provide electricity to the grid in a number of ways, depending on the design and configuration of the CST plant (specifically, the size of the turbine

TABLE 2. **Thermal Energy Storage Technologies**

Substance	Use as Heat Transfer Fluid	Use as a Storage Medium	Considerations for Transfer Thermal Energy to Other Storage Material
Oil, organic mineral oil (Caloria), or Synthetic oil (biphenyl-diphenyl oxide)	Proven in a number of plants.	Low risk but expensive because of cost of the oil (though this is largely a one-time cost, as the oil cycles through the closed system and only needs to be replaced if it leaks). • Oil storage proven at first Solar Energy Generating System (SEGS-1) plant	Via heat exchangers can transfer heat to: • Storage tanks filled with salt mixtures • Research underway on storing in pipes insulated by solid media (ceramic or concrete), and on using Phase-change materials.
Salt mixtures (Blends of sodium nitrate, potassium nitrate, calcium nitrate)	Difficult to use the salt as HTF because of risk of freeze. Research on use as HTF with troughs at ENEA, Italy.	Storage is accepted. • Salt storage demonstrated at tower (Solar Two) • Troughs with salt storage planned for commercial installations in Spain and U.S. • Sener (Spain) and Solar Reserve planning molten salt HTF-storage for towers.	Potentially, but little motivation to pursue given benefits of direct storage.
Water	Accomplished in CLFR configurations, steam is generated directly and sent to power block for steam generation.	Requires storing very large amounts of hot water under high pressure. Options include: • Steam Accumulator Tanks • Cavern storage, or storing heated water under pressure in deep metal lined caverns which can contain the pressure	Heat exchange and storage possible in • Oil (Caloria) • Salt mixtures • Cement or solid media phase change materials

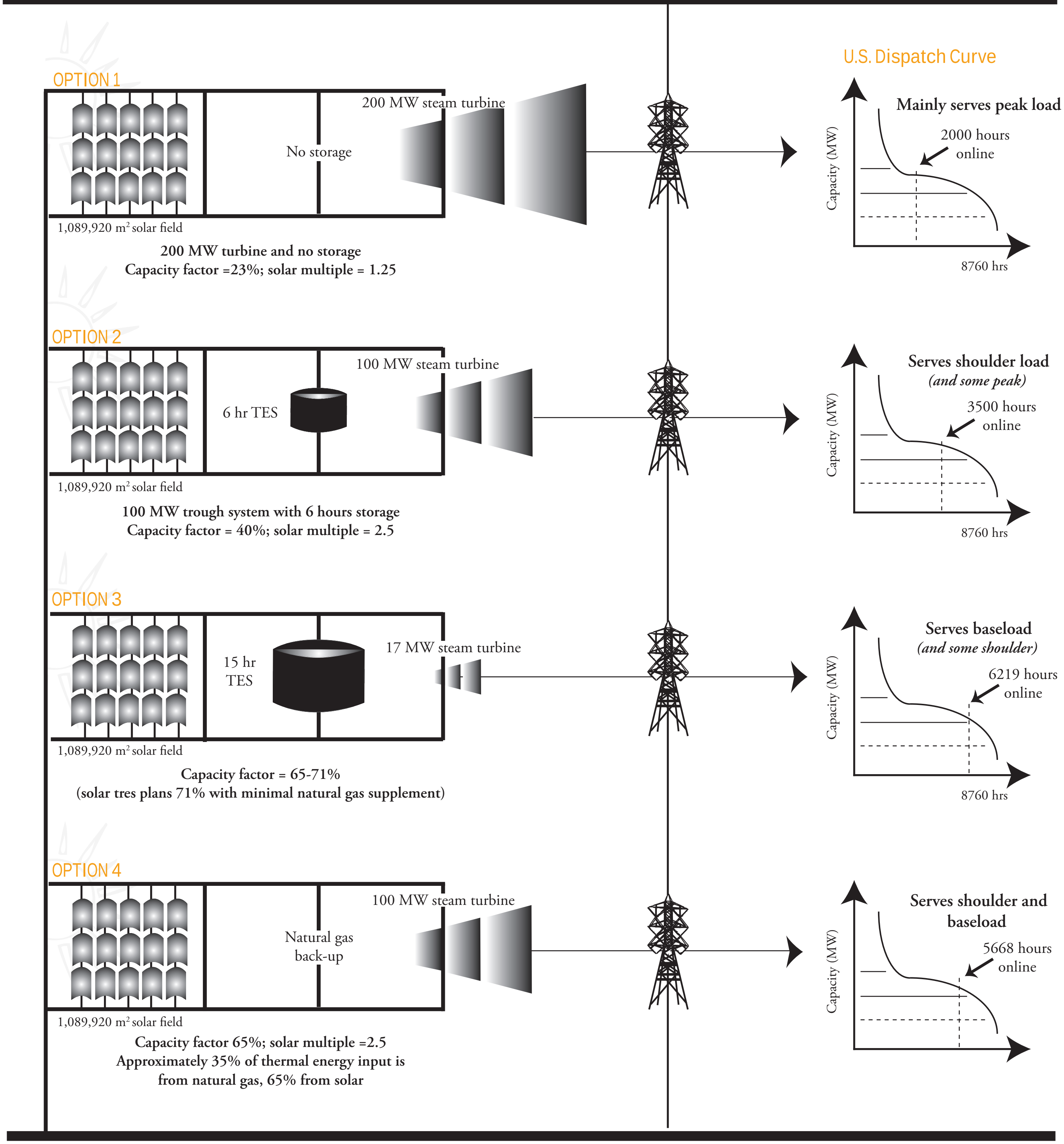
and how much storage is added). A plant developer will opt for a configuration that includes storage if this choice enables the plant to generate power during periods of high demand, into the evening. But if daytime capacity is needed, storage will not likely be added, as CST without storage is already well-suited to provide power in the daytime.

The plant configuration can be optimized to the needs of the utility by balancing the number of hours of thermal energy storage and the plant's turbine capacity (MW). Figure 7 demonstrates several configuration options for a solar field of a given size and illustrates the type of load they can serve given their different generation schedules. Without any storage (Option 1), the field could supply enough energy to power a 200 MW turbine, which would operate at full capacity during the sunny hours of the day. However, with the addition of six hours of storage (Option 2), part of the energy from the field would be stored at any given time, so the turbine would not be as large (100 MW) but would run during more hours of the day. Option 3 illustrates a tower plant with storage, like the Solar Tres plant in Seville, Spain, which will have 15 hours of storage and a small amount of gas hybridization. With such a configuration, the plant should be able to operate all day and night in the summer.[25] Option 4 is a solar–natural gas hybrid plant that achieves a capacity factor close to 65 percent by using natural gas for 35 percent of its energy input.

Adding storage to a CST plant while holding the solar field size constant requires decreasing the size of the turbine. Alternatively, the turbine size can remain constant if the field size (and thus the solar multiple of the plant)[26] is increased. The appropriate field size and turbine size must be carefully balanced, as these have significant economic implications. Increasing the field size adds expenses (more land and collectors), and it incurs an energy penalty that can decrease production.[27] On the other hand, larger turbines enjoy efficiencies of scale. Hence, developers balance these efficiency dynamics as they design a plant that can generate power when the utility values it most.

Utilities value generation the most during times of peak demand, generally in the afternoon and early evening. Currently U.S. utilities' primary option to meet this demand is by dispatching expensive natural gas peaking plants. CST needs no storage to produce power in the middle of the day, and only minimal storage to shift its generation to meet peak demand during the late afternoon and early evening. CST's place in the fuel mix/dispatch curve today is primarily displacing these expensive natural gas generators in providing peaking and shoulder supply. The recently constructed 64 MW Nevada Solar One (the largest CST plant built since 1991) has no storage and an estimated capacity factor of 24 percent.[28] To substitute directly for coal as it is run on today's grid, CST plants would need to achieve capacity factors of 70-80 percent,[29] generating

FIGURE 7. Exploring Different CST Plant Configurations



Sources: *Option 1, 2, and 4 calculated using NREL's Solar Advisor Model with assumptions articulated in Appendix A. Option 3 based on Ortega et al.*

power nearly around the clock and still providing it at a lower cost than coal (see Box 2). The role of coal on the U.S. grid will change, however, with the introduction of a carbon price, which will impact the type of generation valued most highly by utilities, and thus the CST market.

Making CST plants perform more like coal plants and reaching capacity factors of 70 percent and more will require technological advances.[30] Significant research, development, and demonstration (RD&D) could remedy the current technical and economic limits to storage. Improvements could include:

- substituting more efficient heat transfer fluids (HTF),
- proving molten salt storage and direct salt as HTF,
- using thermocline storage tanks (one tank instead of two), and
- developing an efficient storage medium to integrate with direct steam generation. [31]

A study commissioned by U.S. DOE found that with these improvements, capacity factors above 70 percent could be reached on trough plants by incorporating between 9-13 hours of thermal energy storage, depending on the accompanying solar multiple, though it would still be at a cost premium.[32] Towers may, in fact, be a more feasible option for achieving these high capacity factors without fossil backup. As noted above, towers operate at higher temperatures than trough or CLFR plants. The higher temperatures reduce the cost of molten salt storage integration. With higher temperatures (technically, higher temperature differences between the hot and cold storage tanks), storage is cheaper (capital cost per BTU stored) because less salt is required per unit of energy stored.[33]

Although the generation profile of a CST plant without storage differs from that of coal, CST can actually be a better match for meeting the aggregate demand load profile of the grid, including (but not limited to) baseload. One study modeling the output of a CST plant over the course of the year shows that a CST plant with 16 hours of storage can generate power that coincides with hourly grid load some 96 percent of the time.[34] Although these studies pertain specifically to CLFR technology, the general concept is the same for all CST plants, including troughs and towers.

In the near term, CST will likely displace gas generation; at scale, this dynamic would reduce pressure on natural gas supply and make it cheaper. Inexpensive natural gas could compete with some coal plants, particularly under a carbon price, and reduce emissions. Natural gas complements CST on the grid, adding reliability, particularly for generation in winter. Wind is another good complement to CST on the grid, because wind tends to blow more at night than during the day—the inverse generation profile of CST. An integrated portfolio of CST, natural gas, and other renewable energy technologies can play a crucial role in displacing baseload coal. With adequate storage, a CST plant could fill intermittency gaps of wind and photovoltaic (PV) generation, since CST can be ramped up quickly to provide generation during a lull in wind or a cloudy hour.[35] The potential for such integrated use of renewables improves with adequate (and regionalized) transmission and increased regional planning.

BOX 2. Economics of Coal Displacement

As utilities seek to recover investments in existing generating assets and "plug gaps" between growing demand and their generating fleet, displacing existing coal generation in the U.S. will require that CST be competitive at times when coal is on the margin. In the U.S., this typically happens only at night and in the winter (when demand is lower), which does not coincide with periods of high CST output. Moreover, if a coal plant is already up and running, a utility is not likely to decommission it early and fill the gap with a new CST plant without some dramatic change of circumstances (i.e., an extremely high carbon price). Existing generation will be run instead of building new CST (or other) generation, up to the point where the cost to run existing facilities is greater than the cost of new CST generation. In fact, the average age of the current coal fleet is about 35 years old;[36] these long-lived plants supply very low-cost power to the grid. Essentially, the only costs facing a generator under this scenario are production costs, including fuel and operations and maintenance costs. While CST cost reductions are anticipated, it is not realistic to expect CST to compete economically with fully depreciated assets.

Adequately addressing climate change, however, will likely require revisiting this approach. Instead of relying on capacity with the lowest marginal costs and only incremental adjustments to the existing system, utilities, regulators, and policymakers will need to think about rebuilding the grid in the most efficient and logical way. Given the scale of the challenge and the key role that the power sector will need to play in the solution, incremental changes will no longer suffice, and investment in a portfolio of zero-carbon solutions will be needed, even if it means stranding investments in some high-carbon generation facilities.

Comparing Concentrating Solar Thermal Power with Coal

Cost

To illustrate the cost gap that must be closed for CST to compete with coal, the following cost analysis (see Table 3) compares the economics of coal-fired generation to that of parabolic trough CST technology—the most mature of the CST technologies, for which cost and performance estimates are most widely available. The analysis is based on CST operating in the U.S. Southwest under optimal solar conditions.

The cost estimates for each technology are compared using the levelized cost of energy (LCOE), a financial analysis technique that summarizes estimated lifetime costs as an annualized cost per unit of electricity generation (the details of the analysis are discussed in Appendix A). We assume an investment tax credit (ITC) of 30 percent and capital costs and coal prices in line with current estimates, with no carbon price.

Unsurprisingly, the results of the base case indicate that coal-fired electricity is a significantly lower-cost alternative than electricity produced by a parabolic trough plant. Levelized cost for some of the early trough plants constructed in the late 1980s and the 1990s was estimated as high as $0.24/kWh,[37] although research and development efforts have lowered costs to about $0.16/kWh.[38] Today, there is 425 MW of parabolic trough capacity worldwide, with growing commercial interest in the technology. Most recently, the Nevada Solar One plant was constructed near Boulder City, Nevada, at a cost of over $260 million or roughly $4,200 per kW.[39]

Technologies such as Compact Liner Fresnel Reflectors (CLFR) are modifications of the parabolic trough concept. CLFR, which approximates the parabolic shape of parabolic trough technology, is less efficient but has reduced capital costs due to a low cost structure, a low-cost fixed receiver, and low reflector costs.[40] For instance, the estimated capital cost for Carrizo Energy Solar Farm, a proposed 640-acre project site under development in southern California, is $3,100/kWh.[41] One of the leading manufacturers of CLFR technology, Ausra, reports that the cost of electricity from their plants ranges from $0.10/kWh to $0.12/kWh.[42] Today, there is a small-scale (1-MW) demonstration plant in Australia integrated into a large coal-fired power plant (the Liddell Power Station) and there are plans to expand capacity to 40 MW. In the U.S., Ausra has completed construction of its North American manufacturing and distribution center and is now capable of manufacturing more than 700 MW of solar collectors.

Reliable cost estimates for power towers are relatively scarce. Perhaps the best examples of power tower plants are in Spain. The PS10 plant, which is an 11-MW central power tower plant, has 624 heliostats and was estimated to cost roughly $3,800 per kW to construct.[43] Spain is also home to several additional power tower projects, including the Solar Tres plant, which was expected to be operational in 2009.

Including thermal energy storage at a CST plant can increase the value of its power to a utility, but also increases upfront capital expenditure. For instance, the cost per MW for a plant with 6 hours of storage can run $6,400 per MW versus the $4,200 cost per MW for Nevada Solar One (no storage). However, with storage, the levelized cost of generation ($/kWh) can actually decline, since

TABLE 3. Cost Estimates for Power Generation

Factor	Pulverized Coal	Trough (6 hrs Storage)	Trough w/ ITC (6 hrs storage)
Capacity (MW)	500	200	200
Capacity Factor (%)	85%	40%	40%
Capital ($/kW)	2,290	6,044	6,044
Fixed O&M ($/MWh)	29.11	50.00	50.00
Variable O&M ($/MWh)	4.85	0.71	0.71
Fuel ($/MMBtu)	1.92	0.00	0.00
Real LCOE (¢/kWh)	**6.26**	**15.36**	**11.37**
Nominal LCOE (¢/kWh)	**7.91**	**19.42**	**14.38**

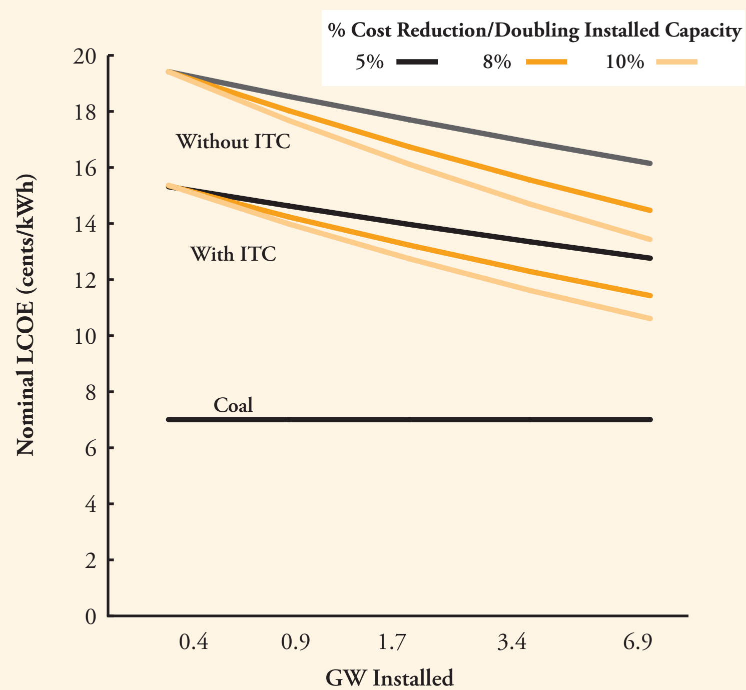
Source: *World Resources Institute based on NREL's Solar Advisor Model* storage increases the annual generation output (kWh) over which to spread the initial capital outlay. Some models of CST systems suggest that at the current cost of storage technology, 6-9 hours of storage capacity results in the optimal LCOE, but the improvement over no storage is fairly small.[44] Indeed, most planned projects in the U.S. do not include storage. Although storage might allow a plant to generate later in the day, if CST cannot compete with the cheaper plants that bid power at that time, it has no market and thus no revenues for such generation.

Narrowing the Gap: Cost Reduction via Learning

The analysis above presents a static snapshot of the current cost differential between coal and CST. Absent technological innovation, this gap could only be narrowed through policies that subsidize CST or penalize coal. However, the cost of CST is unlikely to be static, and will likely be reduced through learning effects, mass production, and economies of scale, narrowing the cost gap with coal (see Box 3 and Figure 8).

Despite the difficulty of predicting learning rates, several studies have estimated the cost reduction potential for CST from learning. For example, the International Energy Agency (IEA) uses a 10 percent drop in cost as a function of learning for concentrating solar thermal technologies.[51] A model developed by the National

FIGURE 8. Reductions in LCOE through Learning, Shown vs. Coal (Trough)



Source: *World Resources Institute with data from NREL's Solar Advisor Model*

BOX 3. Learning

There is a long history to the concept of learning rates for reductions in technology costs. Based on observing results of airplane mass-production during World War II, "technological learning" or "learning by doing" describes the cost reductions that come through experience as a new technology moves from the lab to demonstration and ultimately commercialization.[45] Learning involves the mass manufacture of components and years of experience installing and operating the technology, which allows companies to reduce costs through "learning by doing", optimizing and economizing their processes. It is typically expressed as a learning rate measured as a percentage reduction in unit cost or price of a technology as a function of the level of deployment–for every doubling of installed capacity or production, for instance.[46] Learning rates are difficult to separate from technological innovation and breakthroughs, which might be spurred by research and development (R&D) in addition to deployment.[47]

The learning curve concept has been applied to design and assess public interventions or investments in energy technologies for decades.[48] Much of the funding provided by governments and multinational development banks is rooted in or tied to the concept of a learning effect. When technologies that offer a public benefit are not economically viable, domestic and international policymakers seek to lower the levelized costs to a more competitive level through public investment in deployment of such technologies.

For instance, in its Operational Program aimed at reducing anthropogenic greenhouse gas emissions, the Global Environment Facility (GEF) promotes deployment of newer low-emission technologies whose costs remain above competitive levels, because "through learning and economies of scale, the levelized energy costs will decline to commercially competitive levels."[49] Several analysts made the case for the potential of solar power, particularly CST, in contributing to energy access and GHG mitigation goals with GEF support, which helped influence the design of GEF's programs.[50] In the United States, the Energy Policy Act of 2005 established a Loan Guarantee Program through the Department of Energy to promote the early commercial use of renewable energy technologies. This program is based on the theory that funding deployment of renewable technologies that are not yet economically viable will result in a learning effect and reduce levelized costs.

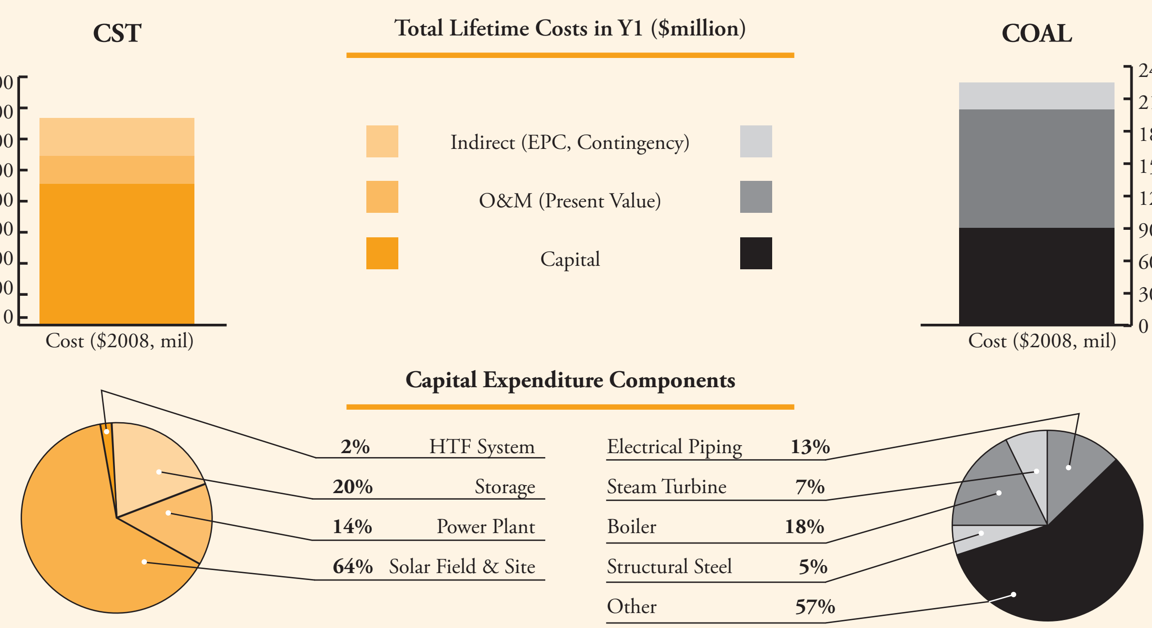
Renewable Energy Laboratory (NREL) uses an 8 percent drop for parabolic trough technology.[52] A study conducted to inform the U.S. DOE's solar plan modeled learning for advanced parabolic trough technology to determine cost reduction below a present baseline.[53] Their research shows that the effects of learning could help drive the price down below $0.06 /kWh (real 2006 dollars) after 4,000 to 8,000 MW have been installed.[54] Learning rates for advanced concentrating solar thermal technologies, such as power towers, should be higher because there is far less existing experience with these technologies.[55]

Opinions vary on the potential for CST to achieve cost reductions through learning. There are industry experts who argue that CST technologies, particularly troughs, have a low learning potential because the technology is a composite of components (mirrors, support structures, collector tubes, turbine-generators, and storage tanks) that are already produced individually at very large scale. Due to this manufacturing specialization, cost reductions through manufacturing improvements will likely be minimal, according to this view. Furthermore, materials costs for these components have sharply escalated over the past few years, a trend which, if it continues, threatens to counteract the effects of any learning. On the other hand, competing technologies, including coal, have experienced similar impacts from commodity price fluctuations, as well as the cost of their fuel. While it may be possible to reduce costs through more efficient manufacturing processes, cheaper materials, optimized plant designs, or more efficient installation, it is not clear whether these cost reductions will follow the anticipated learning curves.

Reflecting a moderate range of cost reductions, Figure 8 demonstrates the potential impact of reductions in CST's LCOE on the gap between CST and coal.[56] The authors do not attempt to show cost reductions possible from rapid technological advancement or unanticipated breakthroughs; however, it is widely documented that cost reductions through technical improvements are available for both troughs and towers.[57]

While it is clear that concentrating solar thermal technologies can play a key role in reducing GHG emissions, these alternate investments will not likely be made if the cost of CST is not reduced significantly. Unless dramatic CST learning takes place, fuel prices drastically increase, or there is a significant charge applied to carbon emissions or other environmental externalities of coal, electricity derived from CST will remain more costly than coal-fired electricity.

FIGURE 9. Cost Breakdown of CST vs. Coal—Lifetime Cumulative Costs



***Source:** World Resources Institute with data from NREL's Solar Advisor Model*

Capital and Operating Inputs

This cost differential is, in large part, due to the increased upfront capital that CST requires relative to coal. This upfront capital includes commodities such as land, glass, steel, and concrete. During operation, the primary input is water (see Table 4).

As the table indicates, CST is exposed to commodity price volatility, accounting for some of the LCOE differential between CST and coal. However, as long as commodity prices remain under pressure from cyclical downturns in global economic activity, CST appears positioned to benefit disproportionately relative to coal (see Figure 9). Moreover, as CST benefits from learning, developers may be able to reduce CST's input requirements for certain commodities. For instance, in 2008 Skyfuel unveiled a new trough design using glass-free mirrors and aluminum frames, which it claims is 30 percent lighter per unit of mirror area than the best of today's designs.[58]

Also worth noting is CST's distinct advantage over coal, in terms of commodity price fluctuation, over the lifetime of the plant. CST plants have no fuel costs, while coal plants are exposed to coal price increases. Moreover, as discussed on page 39, climate policy and the likelihood of caps on carbon emissions will adversely impact coal investments more than CST. CST is not completely insulated from carbon price impacts, however. The cost of inputs like concrete and steel will likely rise, as producers of these commodities also face compliance costs from climate policy. These added costs will be passed through to consumers, including power producers.

TABLE 4. Capital And Operating Inputs: CST vs. Coal

	Component	Coal-Fired Plant (500 MW)	CST Cluster[a] (10 x 100 MW)
CAPITAL	Land	124-494 acres (IAEA, 1997)	4,942-9,884 acres (NREL, 2002; Brightsource, 2007)
	Glass	N/A	120,000 metric tons (DLR, 2004)
	Steel	49,000 metric tons (Pacca & Horvath, 2002)	250,000 metric tons (DLR, 2004)
	Concrete	80,000 cubic meters (Pacca & Horvath, 2002)	200,000 cubic meters (DLR, 2004)
OPERATING	Water	Closed-loop PC: 600-660 gal/MWh** (NETL, 2002) Closed-loop IGCC: 360-540 gal/MWh** (NETL, 2002) Open-loop once-through: 20,000-50,000 gal/MWh (DOE, 2006)	Trough: 768-957 gal/MWh (DOE, 2006) Tower: 758-787 gal/MWh (DOE, 2006)
	Fuel	0.33 tons of coal/MWh (IAEA, 1997)	N/A

[a]Assuming capacity factors of 80 percent for coal and 40 percent for CST, ten 100 MW CST plants will generate the same amount of electricity as a 500 MW coal plant.
* Derived from estimates for 100 MW parabolic trough plant with 8-hour storage capacity.
** Source does not distinguish whether figures are for water withdrawal or consumption.

> ***"Including thermal energy storage at a CST plant can increase the value of its power to a utility."***

Finally, water usage is a concern, as CST plants are most economically competitive in regions like Nevada or the Sahara where water scarcity is already an issue (see Box 4). Like many new thermal power plants, most CST plants employ wet cooling towers to condense the process steam for recirculation. This cooling process is water-intensive, requiring 750–920 gallons of water for each megawatt-hour of generation, depending on the CST technology used. All CST plants also require water—in the range of 8–37 gallons per megawatt-hour—to clean the array of mirror collectors.[59]

As noted above, the majority of the water usage in a CST plant serves to cool the exhaust steam for recirculation. Alternative cooling systems with significantly lower water requirements do exist, but are more expensive and can reduce plant efficiency. Dry cooling systems—where exhaust steam is cooled using ambient air rather than water—reduce water usage by 90 percent, but can add 2–10 percent to levelized costs[60] and reduce the plant's efficiency by up to 5 percent.[61] A variety of wet/dry hybrid cooling systems offer up to an 80 percent reduction in water usage with more modest cost and efficiency penalties.[62] Decisions regarding the choice of cooling system are site-specific, and will depend upon the local climate and cost of water.

While the aridity and water shortages common to many of the most suitable regions for CST create a dilemma for developers, there are also opportunities. As a thermoelectric process, CST creates heat in addition to electricity. Most of these arid regions will have little demand for heat to warm buildings due to already high ambient temperatures, but other uses for this heat exist, particularly for use in seawater desalination (see Box 5).

BOX 4. Water Scarcity

Concerns about water usage have the potential to significantly constrain CST development. Many regions suitable for CST development are already arid, and frequently have limited and shrinking water resources. The impacts of climate change will likely exacerbate concern regarding adequate water supplies for CST plants, since the regions in which CST is most economically competitive are projected to grow drier as global temperatures continue to rise.

There is near unanimous agreement among climate models used in the Intergovernmental Panel on Climate Change's Fourth Assessment Report that the climate in subtropical regions such as the American Southwest and Middle East–Northern Africa (MENA) will grow more arid over the course of the next century.[63] Due to anthropogenic climate impacts and rising demand for water, estimates now indicate a 50 percent chance that Lake Mead—upon which many of the CST facilities planned for the Southwest will rely—could dry up completely by 2021.[64] Climate change is also causing rapid retreat of the Himalayan glaciers, which feed rivers serving half the human population.[65] While in the short term, this glacial melt may actually increase flows in rivers like the Indus, Ganges, and Yangtze, over the long term, once the glaciers are gone, reduced river flows could lead to severe water shortages during the dry season—when glacial melt is a critical source of freshwater in countries like India and China.

In terms of long-term strategic planning, CST developers and policymakers concerned with the security of energy supplies must weigh not only how much water is used, but also whether adequate water supplies will continue to be available.

BOX 5. Desalination

Water scarcity is a growing concern worldwide, but the problem is especially acute in arid regions. Desalination—the process of removing salts and minerals from available water resources to produce fresh water suitable for irrigation or human consumption—is an expensive and energy-intensive process. It is mainly used in the Middle East where desalination plants are powered with cheap energy from natural gas and oil. CST technology could provide an opportunity to reduce emissions from desalination plants more cost-effectively than would be feasible with other renewables. Wind and photovoltaics produce no heat, so any electricity used to power desalination is electricity that could have been sent to the grid. As CST produces power and waste heat, it is more efficient for desalination than many other renewable energy sources.

SECTION III

Deploying CST at Scale

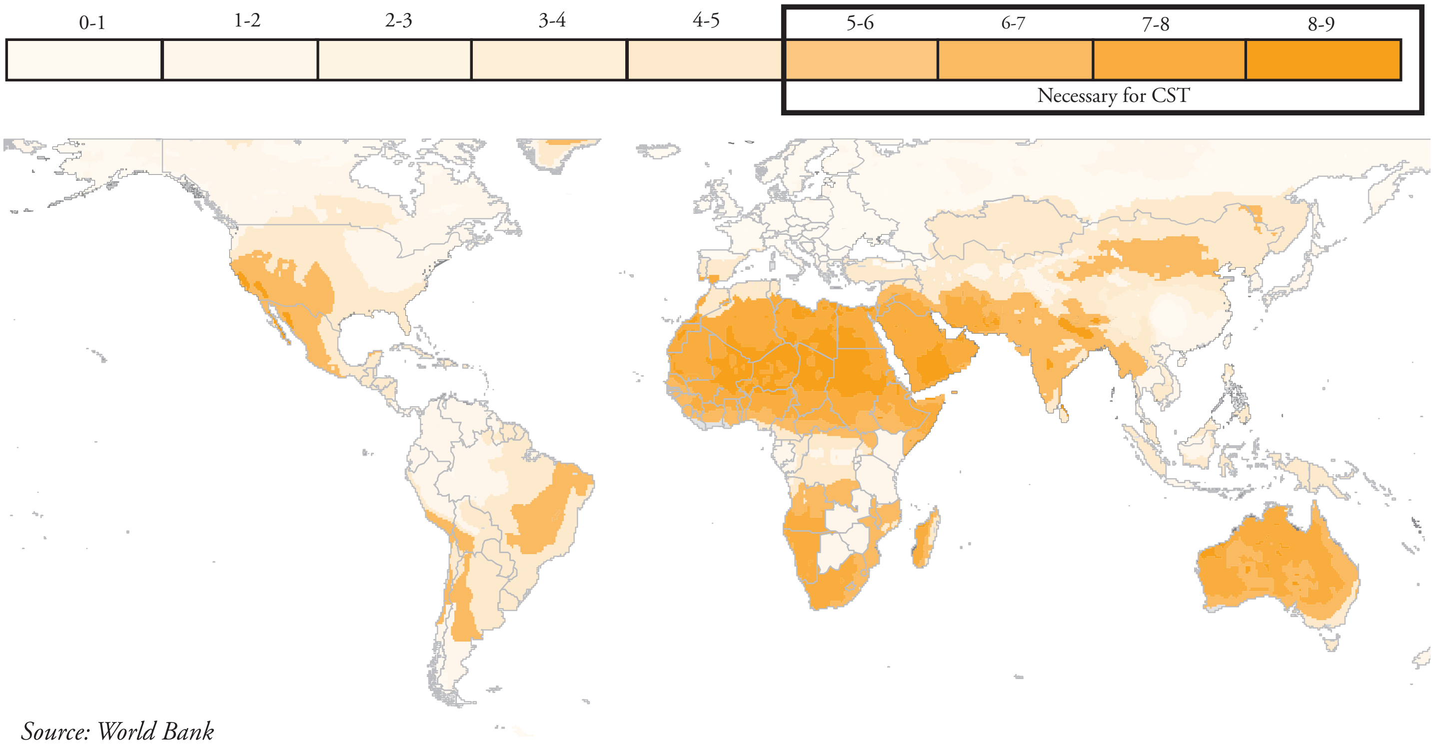
potential and barriers in key countries

In terms of technology performance, CST can feasibly displace coal, but where will this work in practice? There is great potential for achieving significant emissions reductions through CST deployment in key regions. Where CST deployment can have the most GHG-reduction impact depends on two fundamental factors: the amount of sunlight available (DNI) and the coal intensity of the electricity mix.

Achieving large-scale emissions reductions from CST will require tapping into areas of high solar radiation around the globe. Direct insolation of around 5.5 kWh/m^2/day is considered a minimum requirement for CST development, but significantly higher DNI is much preferred if costs are to be kept to an acceptable level.[66] Most of the suitable areas are found in arid and semi-arid areas. While available DNI estimates vary, and local conditions should be carefully verified before projects are developed, global resource assessments indicate that the most favorable conditions for CST deployment are in the U.S. Southwest, South Africa, Australia, Northern Africa, and the Middle East. Spain, Brazil, and parts of India and China also have suitable conditions (see Figure 10 for one such assessment).[67] Of these, the U.S., India, and China also have significant and growing emissions from coal-fired power (see Table 5). Displacing coal-fired emissions through CST deployment in these regions could make a significant contribution to global climate stabilization.

Achieving large-scale emissions reductions from CST deployment will require a major scale-up of current efforts. In this section, we explore the potential for CO_2 reductions from CST displacing coal in several countries and global regions with suitable solar resources and significant and growing coal-fired power generation. The analysis highlights historical experiences with and barriers faced by CST initiatives in these countries and regions.

FIGURE 10. **Global Direct Normal Solar Radiation (kW/m²/day)**



Source: World Bank

TABLE 5. **Select Countries with Good Solar Resource Potential**

Country	Fuel Mix*	Emissions ($MtCO_2$) from electricity and heat, 2004	Advantages/Disadvantages
U.S.	50% coal; 19% nuclear; 18% natural gas; 6% hydro/renewable; 3% oil	2,691	Highest solar radiance exists in the southwest, far from the population centers on the coasts.
China	79% coal;16% hydroelectric; 2% nuclear; 2% oil	2,531	Highest solar radiance exists in southwest and Inner Mongolia, far from the population centers to the East.
India	69% coal; 14% hydroelectric; 9% natural gas; 4% oil 2% nuclear	662	Areas of high solar radiance are located near population centers. However, India's electrical grid suffers from reliability issues.
MENA	59% natural gas; 30% oil; 8% hydroelectric; 3% coal	727	With abundant solar resources, CST could displace local fossil fuel generation while excess power is wheeled to Europe and other parts of Africa.
Brazil	84% hydroelectric; 5% natural gas; 3% oil; 2% coal; 2% nuclear	56	Wet climate: moisture in air diffuses sunlight, reducing CST-quality resource potential.
South Africa	94% coal; 5% nuclear; 1% hydroelectric	214	Suffering from reliability issues, thus building significant new capacity. Areas of high solar radiance near population centers.
Australia	80% coal; 12% natural gas; 6% hydroelectric; 1% oil	218	Good resource around the country.

** Where percentages do not add up to 100%, difference is attributable either to rounding or to renewables other than hydroelectric power.*
Sources: World Bank, World Development Indicators (2005 data); CAIT 2004

United States

In the U.S. Southwest an enormous solar energy resource base remains largely untapped. Here the amount of solar energy that falls on an area the size of a basketball court over the course of a year is the equivalent, in thermal energy terms, of about 650 barrels of oil.[68] Although near-term deployment of the technology will be limited by transmission constraints, environmental and siting concerns, and terrain characteristics, the potential is large.

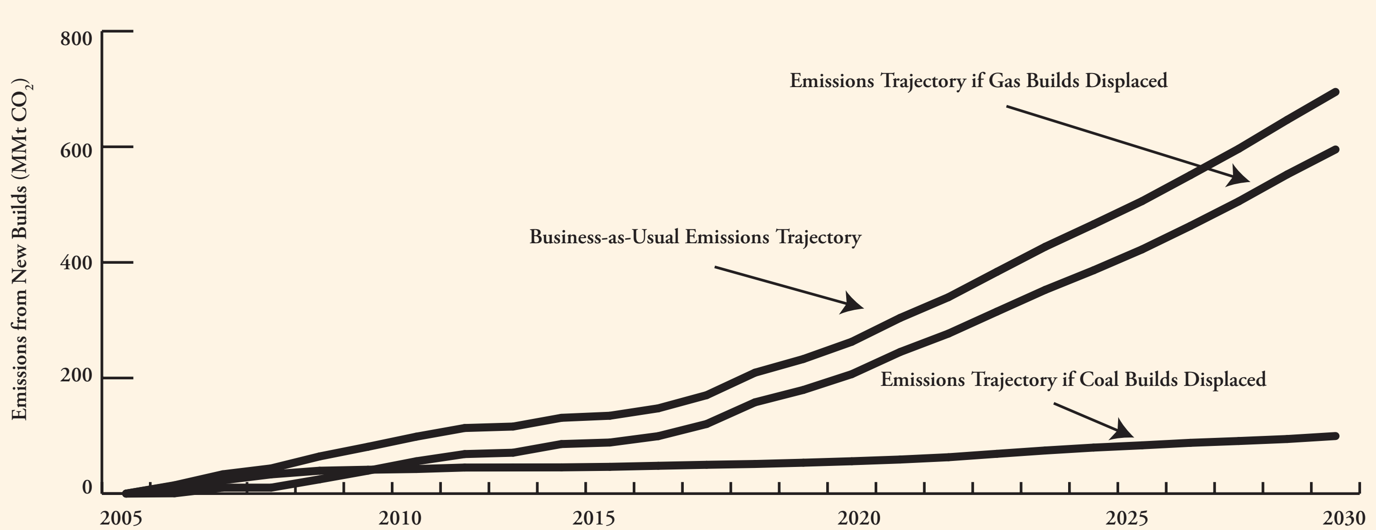
The first commercial CST plants in the U.S. were built in the Southwest. LUZ Industries built nine CST plants in California in the late 1980s as part of the Solar Energy Generating Systems (SEGS). They use natural gas backup for up to 25 percent of their primary energy. There are several new plants and plants under construction in the region as well. For example, Acciona built a 1-MW plant in Arizona that became operational in 2006, and their 64-MW Nevada Solar One plant was completed in 2007.

Further CST deployment could displace significant amounts of CO_2 emissions from coal in the U.S. Displacing all projected coal-fired capacity additions to 2030 in the Southwest with about 175 new 200-MW CST plants would reduce emissions by more than 1 billion tons.[69] (For a complete discussion as to the assumptions used in this modeling, please refer to Appendix B.)

The U.S. power sector relies heavily on coal-fired generation, with an additional 96 GW of coal-fired capacity to be built by 2030, according to Energy Information Administration (EIA) forecasts.[70] In theory, constructing 194 GW of CST could eliminate the need for this new coal-fired capacity and would displace 5.3 billion tons of CO_2 emissions[71] (see Figure 11).[72]

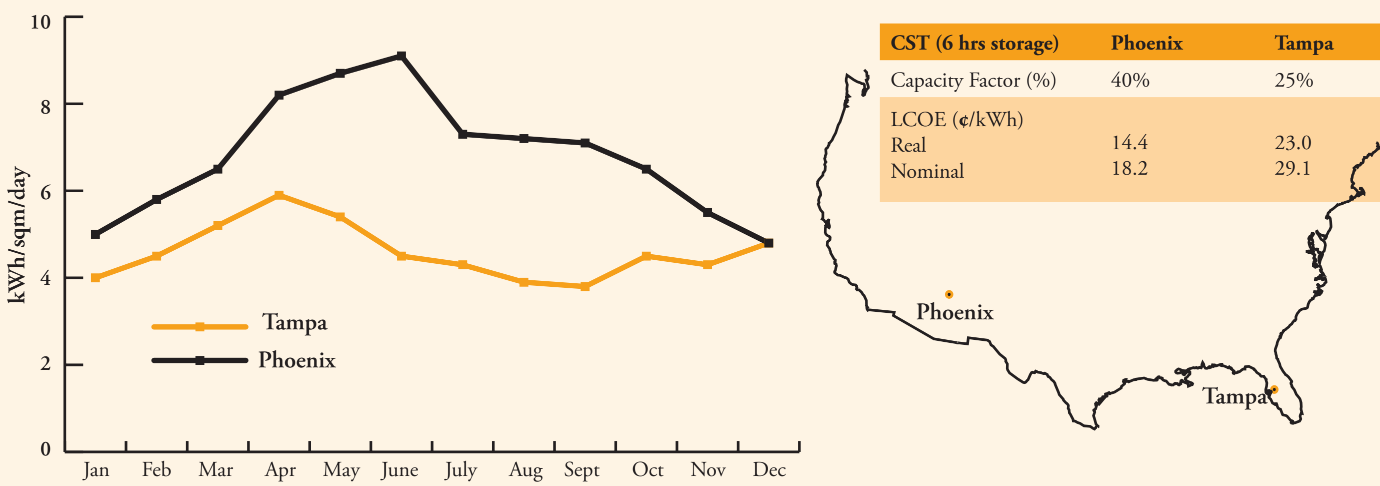
However, much of the coal-fired electricity generation in the U.S. takes place outside the Southwest, in areas where solar resources are not optimal. For example, although sunny Florida might seem like a good option for developing CST on the East Coast (in fact, companies are exploring this option already), lower DNI levels (due to higher levels of water vapor in the atmosphere) greatly reduce the potential output of a Florida-based plant. As such, electricity produced from a Florida-based plant costs significantly more than a plant located in a more favorable region such as Arizona (see Figure 12). Given the reduced output and lower profitability of CST plants located outside the Southwest, it is unlikely that significant capacity will be installed in other parts of the country.

FIGURE 11. Projected CO_2 Emissions Trajectories from Displacing New Fossil-Fueled Electricity in the United States, 2006-2030



Source: *World Resources Institute, based on 2005 EIA data*

FIGURE 12. Solar Radiation Varies with Latitude and Location



CST (6 hrs storage)	Phoenix	Tampa
Capacity Factor (%)	40%	25%
LCOE (¢/kWh)		
Real	14.4	23.0
Nominal	18.2	29.1

Source: *National Renewable Energy Laboratory (NREL)*

Given the scale of the emissions-displacement potential nationwide, however, developing CST resources in the Southwest remains an attractive option for meeting the country's growing energy demand. With significant upgrades and changes to the country's transmission infrastructure, CST could be integrated into the U.S. fuel mix, provided the cost barriers were also addressed. Significant additional transmission infrastructure would be required to ship power from its point of generation—in Arizona, for example—to areas of high consumption throughout the U.S., including relatively close cities such as Los Angeles. Changes to the transmission infrastructure would need to include substantial capacity additions as well as significant regulatory and technological transformations.

Traditional alternating-current (AC) technology, which makes up 98 percent of today's grid,[73] is of limited use for wheeling CST power across the country, as heavy line losses make it uneconomical for power transmission over long distances.[74] For example, although West Coast demand centers are closer, major load centers on the East Coast are roughly 3,000-4,000 km (1,800-2,500 miles) from the resource-rich areas where CST might be built. Over the distances from an Arizona-based CST plant to the major demand centers in the East, an estimated 45 percent of the power generated would be lost in transmission.[75]

There are several ways this new transmission infrastructure could be built. It is clear, however, that the infrastructure required to span this distance and enable such displacement could not be built on an incremental, project-by-project basis, but rather would require a major overhaul of the transmission system at the national level, which will be a difficult undertaking.

Several different ideas are currently being discussed for linking the national grid or simply connecting remote generating sources with demand centers, including making use of recent advances in both alternating current (AC) and direct current (DC) technologies. For instance, American Electric Power (AEP) has analyzed the transmission needs to enable wind to power 20 percent of the U.S. national grid, proposing an integrated national transmission system overlay using 765-kilovolt (kV) AC lines.

Others have proposed a "national backbone" approach relying on a system of high-voltage direct current (HVDC) lines to transmit solar energy from the Southwest around the country.[76] HVDC lines can transmit electricity efficiently over long distances, incurring losses of only about 3 percent per 1,000 km, compared to losses of 8 percent on 750-kV AC lines.[77]

Although few proposals are specific regarding implementation, it is clear that this type of infrastructure build would be an expensive undertaking. The figures vary widely, according to differing assumptions about what is required, but they give a sense of the scale of the needed investment. For example, AEP's proposed national transmission system overlay using 765-kV lines would cost an estimated $60 billion.[78] T. Boone Pickens claims that his plan to power 20 percent of U.S. electricity needs from wind resources in the Midwest would entail $200 billion of investment in transmission infrastructure.[79] These estimates represent a sharp increase relative to recent spending on transmission infrastructure, with only about $50 billion in cumulative transmission investment (integrated and by stand-alone companies) from 1999 to 2008 (2005 data, actual and planned).[80] However, compared with the trillions of dollars proposed and committed for economic stimulus packages around the world, much of it intended for infrastructure projects, the figures may seem somewhat more reasonable. Moreover, the transmission system has suffered from decades of underinvestment, and these efforts could include the badly-needed system upgrades that would improve reliability and efficiency, and enable the large-scale deployment of plug-in electric vehicles.

Given the scale of the investment, the division or allocation of capital costs and the speed of cost recovery are both critically important. Currently, transmission capital costs are borne by the transmission owners or the utilities that build, operate, and use them. However, given current incentive structures, such a massive expansion and transformation of the national electricity transmission system will need to be a federal-level undertaking. Therefore, it is not informative to factor in a single cost number for the transmission costs or portions of costs of transmission systems that CST plants will incur. The scale of the investment is simply too large to be undertaken by any one company for any one project.

In addition, there are significant regulatory barriers to investment in transmission infrastructure that can carry renewable power from generation source to large demand centers.[81] Given the complexity of overlapping regional, state, and federal jurisdictions, it can be bureaucratically cumbersome and prohibitively expensive to plan and site new transmission lines.[82] States must grant permits for new transmission lines, so projects with lines crossing multiple states must deal with several different regulatory regimes, significantly increasing transaction costs. Federal policy changes, including an increased federal role in transmission planning and/or improved coordination between regional grid operators, will be needed to enable investment in the infrastructure to connect CST regions to areas of high demand.

Finally, a national grid that incorporates significant amounts of CST, generated in the Southwest and transmitted around the country on high-voltage lines, could be far more vulnerable to security risks than today's grid. With such a large proportion of the nation's power being generated in a single geographic location, the destruction or malfunction of just a few key transmission lines could incapacitate entire regions of the country. While an auxiliary power system with more distributed generation and local transmission networks could protect against these security risks, these contingencies will add further costs to any national grid expansion scheme.

> ***"In the U.S. Southwest an enormous solar energy resource base remains largely untapped. Here the amount of solar energy that falls on an area the size of a basketball court over the course of a year is the equivalent, in thermal energy terms, of about 650 barrels of oil."***

India

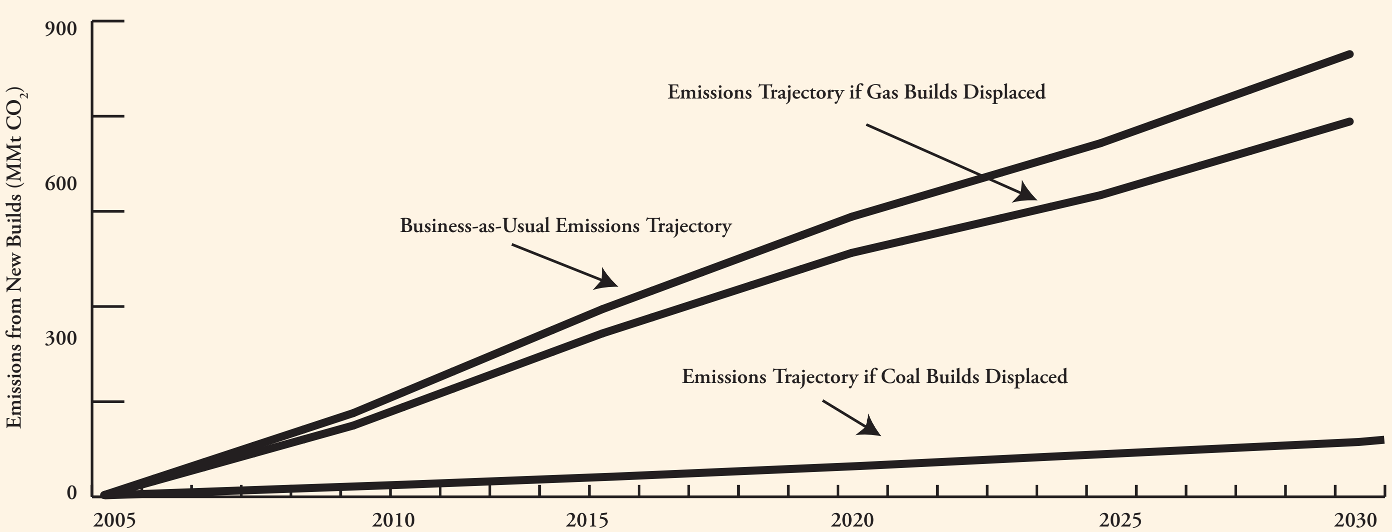
As one of the few places in the world with both a good solar resource and a large consumer base in the same place, India's long-term solar potential is perhaps unparalleled. In most parts of India, there are about 280 clear, sunny days per year, and average insolation incidence across the country is about 4.5–6.0 kWh/m²/day.[83] The Thar Desert of northwestern India has been identified as a prime site for CST development to power densely populated states such as Delhi, Punjab, and Haryana, which lie just to the north.[84] India also has some experience with CST. The country's first solar thermal power plant using parabolic trough technology was built in 1989 but only operated for a few years.[85] More recently, India started project development for an Integrated Solar Combined Cycle (ISCC) plant as part of the Global Environment Facility's CST portfolio, but the project eventually was cancelled (see Box 6).

Coal dominates the Indian electricity sector, accounting for some 69 percent of the country's electricity generation.[86] Coal's dominance is perpetuated for several reasons. India has the world's fourth largest coal reserves, making this abundant resource relatively inexpensive, an important consideration in a country in which a quarter of the population lives in poverty.[87] Moreover, almost half of India's population lacks access to the electricity grid, and as India's economy grows, it creates a major challenge for the power sector to keep up with demand growth. Plagued by energy deficits and power shortages, India has relied on its cheap and accessible coal reserves to build power supply quickly.

Each year, India's coal plants emit roughly 800 million tons of carbon dioxide.[88] According to EIA, reliance on coal-fired power is expected to grow through 2030, with a projected 150 percent increase in coal generation relative to the 2005 level.[89] This new coal-fired capacity would produce an additional 811 million tons of CO_2 emissions from 2006 through 2030.[90] Displacing the 95 GW of anticipated new coal builds in India with 168 GW of CST could yield enormous CO_2 reductions (see Figure 13).[91] However, given India's problems with the current electricity grid,[92] highly centralized renewable energy may not be the optimal solution for the entire country.

> ***As one of the few places in the world with both a good solar resource and a large consumer base in the same place, India's long-term solar potential is perhaps unparalleled.***

FIGURE 13. Projected CO_2 Emissions Trajectories from Displacing New Fossil-Fueled Electricity in India, 2006-2030



***Source:** World Resources Institute, based on 2005 EIA data*

BOX 6. Solar Deployment Initiatives and Lessons Learned from GEFand GMI

In 1996, the Global Environment Facility (GEF) began a program to develop a portfolio of CST projects in developing countries, motivated by the desire to promote "learning by doing" cost reduction for what it viewed as the most promising renewable technology in sunbelt countries. At the time, only the Solar Energy Generating Systems (SEGS) plants in California had demonstrated commercial-scale success with CST, but trough technology was seen as proven.

The GEF initiated four projects, intending to have them operational by 2001.[93] As of 2008 there is one project operating (in Morocco), two under construction (in Egypt and Mexico), and one that will not go forward (in India).[94] All four projects were designed as Integrated Solar Combined Cycle (ISCC) plants, which use a trough solar collector field to supplement thermal input from natural gas into a combined cycle turbine. This design was chosen to lower the cost of energy produced while still promoting learning with the technology. However, the substantial difficulty in coordinating risk sharing between the solar and gas technology providers has proven to be one of the greatest challenges in development.[95] The complications with managing technology risk have been due in part to the lack of familiarity with solar thermal, but were exacerbated because these combined ISCC plants were the first of their kind *in the world.*

Integrating gas combined cycle with solar thermal required cooperation between large, traditional power generation firms and solar thermal technology developers who were operating in a nascent industry and were viewed as riskier counterparties. Modeling the technical interface between the solar and the gas component is sometimes problematic, and the performance of one component depends in part on that of the other. This dynamic made it difficult for either technology suppliers to make performance guarantees without control or serious technical knowledge of the others' technology, which added risk.[96] Intellectual property protection also emerged as a risk between the two types of technology suppliers. Risk sharing on performance was especially difficult when the gas turbine supplier was responsible for guaranteeing the Engineering, Procurement, and Construction (EPC) contract for the whole plant, and may explain the low interest in bidding by industry, which was a problem for several projects.[97] (For context, there were no companies building CST in the U.S. in 2002.) Siting for optimal resource adequacy has also been an issue, which is not surprising for first-of-kind renewable energy projects. Specific experiences and lessons from these projects are discussed below.

Egypt (Kuraymat) – Because of the technology risk, the funders insisted that the project be split into two EPC contracts—one covering the CST portion and one for the gas plant—and financed separately. Though it caused delays, this was eventually agreed on as a solution with Iberdrola and Mitsui.[98] Construction began in early 2008.

India (Mathania) – According to the World Bank, the project "could not be implemented in a timely manner due to inappropriate design and location."[99] The project site selected had a solar resource characterized as "only average"[100] as well as issues with natural gas supply risk, which also caused delays. There was little bidding interest from industry in response to the first Request for Proposal (RfP) (2003), and it failed to secure a bid.[101] Because the government viewed ISCC as risky, it required large guarantees from EPCs—as much as 20 percent of the total investment—until the end of the Operations and Maintenance (O&M) contract. This in turn would have required project developers to raise their expected rates of return (and price of power) or wait five years for payback.[102] In 2004, the government in India changed parties after an election and cancelled the project.[103]

Mexico (Sonora) – The project faced low bidder interest in the first RfP of 2002, and restructuring of the Mexican rules on Independent Power Producers (IPPs) and bidding also caused delays. In 2004, the project was moved to a site with better DNI resource.[104] As of late 2008, the project was under construction, with completion expected in 2009.[105]

Morocco (Ain Beni Mathar) – The first round of bidding attracted little interest, possibly due to "technology uncertainties, market uncertainties, lack of long-term PPA [Power Purchase Agreement]."[106] The project structure was changed from an IPP to an EPC with the national utility owning the project in order to mitigate market/PPA risk. The project is currently under construction and is expected to be fully operating in 2010.[107]

Many of the technical problems experienced during these first attempts at international deployment should not be an issue for future deployment of the technology. The overwhelming majority of CST facilities now planned in developing countries do not incorporate hybrid solar and natural gas technology, and there are now solar thermal EPCs with significant proven experience in Spain, leading to "larger consortia now emerging … and willing to take on the whole project."[108] However, there is still an element of technology risk, real or perceived, which disadvantages CST. Utilities and investment decision-makers are often unfamiliar with CST, while incumbent coal-fired technologies are well-known. Project participants in host countries may also be uncomfortable with assessing the risks of CST. Unlike coal, which can be purchased on global markets for which data are readily available, solar resource data are less available or accessible. Gauging a country's solar resource, even on a macro scale, requires interpreting global satellite data, which currently can only be done by specific research institutes in Europe and the U.S. at a fee. Obtaining project-level data for site selection is expensive and requires at least a year of onsite data collection.[109] In addition, O&M for solar thermal plants requires extreme precision, and finding skilled personnel can be difficult. For developing countries looking to exploit low-cost resources to provide cheap electricity to populations currently lacking it, these cost differences between CST and coal-fired technologies are an important consideration.

China

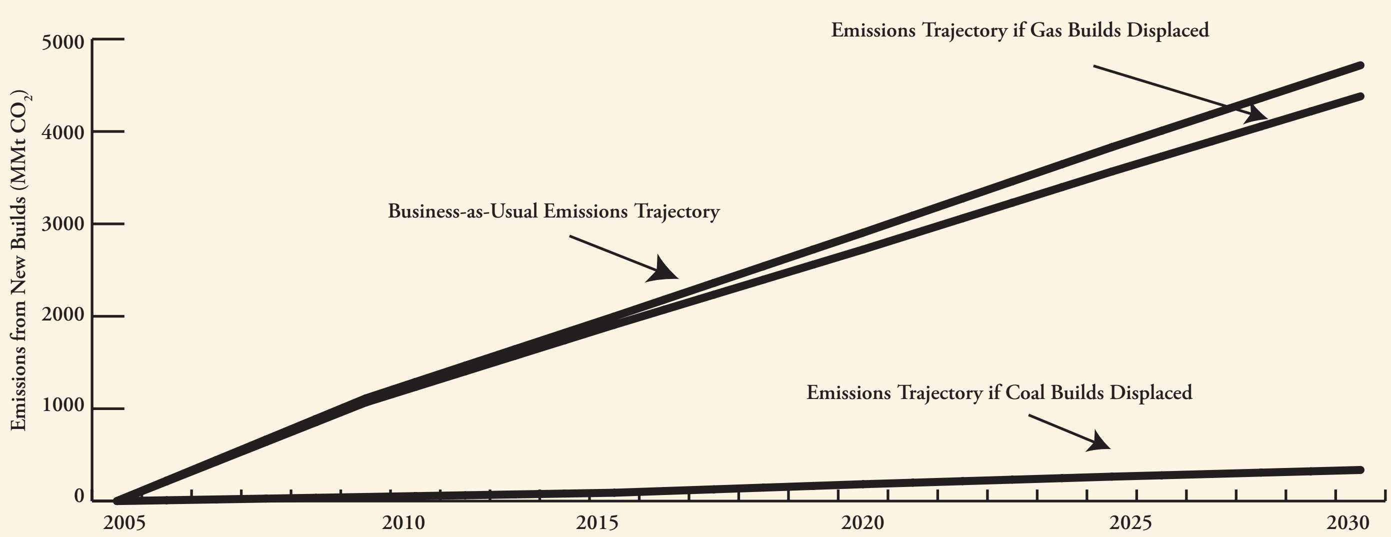
China's solar resources are adequate but not ideal for CST. However, given the carbon intensity of the Chinese power sector, it is worth exploring the coal displacement potential nonetheless. The Chinese government has initiated efforts to tap its solar resources, which are located in isolated regions of the southwest and possibly the Mongolian border regions to the northwest. For example, in 2006 Solar Millennium AG announced plans to develop 1,000 MW of solar thermal power plants by 2020, with the first plant to be constructed in Inner Mongolia. China has also integrated plans for solar thermal power plants into its Five-Year-Plan.[110]

> ***As a generation resource that does not require a fuel input, CST could offer an energy security solution for Chinese power demand.***

Security of energy supply is a major political issue in China. As energy demand continues to grow, China's ability to supply this demand domestically has fallen dramatically. Formerly a net exporter of oil, China became a net importer in 1993, and since that time, energy security concerns have heavily informed Chinese policy decisions.

Historically, coal has been seen as a secure domestic resource. However, despite the country's vast coal reserves, China was a net importer in 2007. Mines can barely produce enough coal quickly enough to satisfy demand, and the capacity of China's rail infrastructure to transport coal from mines to where it is needed is weak. For instance, in early 2008 winter storms shut down the transport of coal from producing to consuming regions, causing electricity shortages.

FIGURE 14. Projected CO_2 Emissions Trajectories from Displacing New Fossil-Fueled Electricity in China, 2006-2030



Source: *World Resources Institute, based on 2005 EIA data*

As a generation resource that does not require a fuel input, CST could offer an energy security solution for Chinese power demand. However, China's solar resources are strongest in remote areas far from the population centers in the East, where electricity demand is strongest and growing. To fully tap into these resources would require long-distance transmission lines across the rugged terrain of the western and central parts of the country, creating a new source of energy security concerns. In addition, water scarcity and water-supply security are increasingly a concern in China, so CST developers will need to reduce their water consumption or plan carefully in order to be a viable solution to China's resource constraints.

Coal-fired power accounts for roughly 80 percent of China's electricity production, and construction of coal plants continues at a brisk pace.[111] With its growing appetite for energy, China is expected to rely heavily on its massive coal reserves well into the foreseeable future. The EIA estimates that China will build 734 GW of new coal plants—almost 2.5 times current generating capacity from coal—from 2006 to 2030.[112]

Large-scale development of CST in China could have a dramatic impact on the nation's emissions trajectory. Carbon dioxide emissions from new coal-fired capacity could approach 60 billion tons from 2006 to 2030 (see Figure 14).[113] It seems unrealistic that CST could displace all new coal-fired builds in China through 2030, which would require a colossal 1,288 GW of CST.[114] However, the sheer scale of the projected new coal builds means that even a partial displacement could result in significant emissions reductions.

Middle East and North Africa (MENA)

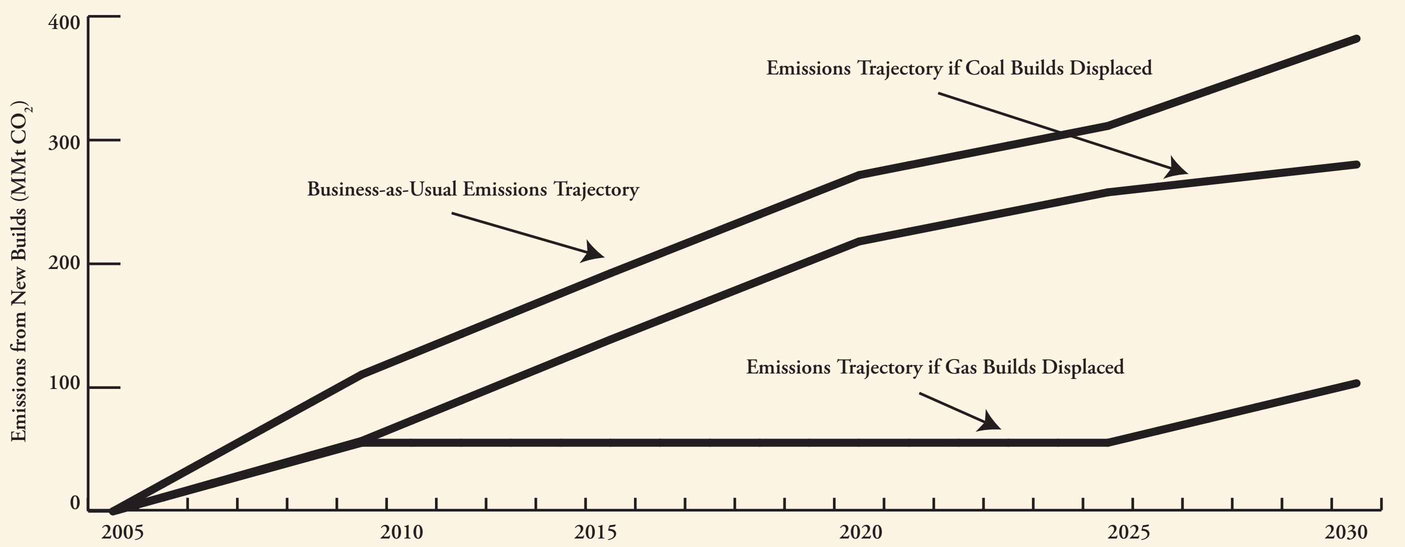
Desert countries such as those in North Africa have rich solar energy resources which, if exploited at scale, could not only meet domestic electricity demands but could also be an electricity source for neighboring Europe. It is estimated that the amount of solar resource striking 6,000 square kilometers of desert in North Africa could supply thermal energy equivalent to the entire oil production of the Middle East—some 9 billion barrels a year.[115]

North Africa's electricity mix is not carbon-intensive; thus, displacing domestic generation with CST does not offer significant potential for CO_2 emission reductions. However, there is potential for North African CST to displace considerable emissions from coal- and natural gas-fired electricity in neighboring Europe. According to EIA estimates, generation from natural gas and coal is projected to increase by a combined 72 percent by 2030 in the European countries of the Organization for Economic Cooperation and Development (OECD),[116] with CO_2 emissions estimated to climb an additional 5,535 million tons.[117]

Primarily due to carbon constraints already in place in Europe, power builds in the region over the next 25 years will likely include little coal-fired capacity. From 2006 to 2030, Europe is projected to construct 208 GW of natural gas capacity, compared to less than 17 GW of coal capacity.[118] As Europe is decommissioning rather than building new nuclear capacity, its reliance on natural gas for future baseload power generation will likely increase. Thus, unlike other countries examined for this study, it is displacement of natural gas that presents the greater opportunity for emission reductions.

> ***It is estimated that the amount of solar resource striking 6,000 square kilometers of desert in North Africa could supply thermal energy equivalent to the entire oil production of the Middle East—some 9 billion barrels a year.***

FIGURE 15. **Projected CO_2 Emissions Trajectories from Displacing New Fossil-Fueled Electricity in OECD Europe, 2006-2030**



Source: *World Resources Institute, based on 2005 EIA data*

While the countries of OECD Europe do not have sufficient DNI to cost-effectively produce CST to displace gas-fired generation, the countries of the MENA region do. Rather than constructing 208 GW of gas-fired capacity, Europe could instead finance the construction of 280 GW of CST capacity[119] in the MENA region and then negotiate contracts with the MENA nations to wheel the power to Europe over high-voltage transmission lines. This alternative strategy would displace almost 4.2 billion tons of carbon dioxide from 2006 to 2030 (see Figure 15)[120]—more than three times the possible reduction from displacing new coal builds in Europe.

Trans-Mediterranean energy collaboration involving CST has already begun taking shape. The Union of the Mediterranean—consisting of European and MENA countries—has endorsed the Mediterranean Solar Plan, which calls for developing 20 GW of energy from solar and other renewable energy resources in MENA countries by 2020.[121] The majority of the generation is expected to come from CST and the Plan allows for electricity exports to Europe transmitted via high-voltage lines. Such a proposal for a trans-Mediterranean energy network has broad implications for European energy security. On one hand, a vast inter-regional CST network connected by just a few arteries of high-voltage transmission line would be exposed to high levels of security risk. The network's ability to deliver power to Europe would be susceptible to a single well-placed attack or technical malfunction. On the other hand, electricity imports from CST plants in the MENA region would provide critical diversity to Europe's energy supply. By 2030, Europe is projected to rely on natural gas for 40 percent of its power generation, with roughly half the supply coming from Russian imports.[122] The delivery of electricity from CST under the Mediterranean Solar Plan would ensure a more diverse and secure energy supply.

SECTION IV

Policy Options

leveling the playing field for CST

New technologies require policy support in the early stages in order to compete with incumbents. Surveying experience to date in key developed countries, this section explores the domestic policy support options that can enable CST to penetrate local electricity markets. It also looks to experience with international efforts to deploy CST and draws conclusions for international policy interventions.

National Policy Options

To date, there has been limited experience with the range of in-country policy support mechanisms for CST development and deployment. However, it is possible to draw some lessons from experience in Spain and the U.S. and apply those lessons to CST-deployment policies going forward, particularly to measures which could incentivize CST development to displace coal.

Policy options to accelerate deployment of CST fall into two main categories. Some "push" the technology into the market through subsidies and by promoting cost reductions via R&D and technological advances, while others "pull" the technology into the market by increasing the cost of incumbent technology alternatives or mandating use of renewables, creating a guaranteed market for the power produced.

Various "push" policy options are available to support CST deployment while the industry matures and costs come down (see Table 6). These policies can be structured to reduce the cost of renewable generation, or they may provide a subsidy to generators of renewable energy, allowing them to sell at below-cost prices. Among the "push" options, feed-in tariffs are distinct from tax credits, waivers, and most other incentives, in that the policy directly raises the price paid for renewable generation and guarantees it a buyer over a period of time.

"Pull" options focus on market-creation policies that pull a new technology into commercial deployment. A stable market for CST generation increases the likelihood of opportunities to contract plants using new technologies as well as a market for component parts once a new manufacturing facility starts producing them. Policies that could pull CST into the market include mandating the use of renewable energy via portfolio standards, as well as policies (such as cap-and-trade or a carbon tax) that increase the cost of the incumbent technology by pricing in associated externalities (see Table 7).

TABLE 6. "Push" Policy Options

Type of Policy	Description	Pros/Cons for Strategic Displacement of Coal	Example of Use
Investment Tax Credit (ITC)	A tax credit on a percentage of the total capital investment in a renewable energy project. Helps mitigate high start-up costs for renewable energy projects.	The current 30 percent ITC in the U.S. significantly reduces LCOE, helping CST compete with coal. Tax-based incentive can be captured only by developers or partners with significant tax liability.	U.S.: 30 percent for CST projects constructed before 2017. Value is about 3¢/kWh, depending on plant design and cost.[123]
Feed-in Tariff (FIT)	Subsidizes and guarantees a market for CST. Utilities are obligated to enter into long-term contracts in which they pay generators a fixed, above-wholesale price for each unit of renewable energy produced.	Requirement to purchase CST generation at a fixed price, on an as-available basis and at any hour, means that CST may compete with coal around the clock. Whether CST generation displaces existing coal-fired generation depends on time of day and the region's load supply curve.	Spain: Generators must choose whether to receive a fixed-rate feed-in tariff (contracted via PPA), or to sell on the spot market and receive a feed-in premium, which is paid on top of the market price. For the first option, the utility must take the power whenever it is generated, at a FIT of €0.28.6/kWh over 25 years. The above-market feed-in premium is €0.271 for the first 25 years (€0.21 thereafter).[124] Both tariffs are only available to installations up to 50 MW.[125]
Accelerated Depreciation	Allows for more aggressive depreciation of renewable energy assets in the near term. Enables greater tax write-offs in the early years of a project to help cover higher up-front capital costs.	Can reduce LCOE by about 3 cents per kWh.[126]	U.S. – Five years for solar property (with potential bonus depreciation of 50 percent in first year).[127]
Loan Guarantees	Third parties (often governments) guarantee the full repayment of a loan. Helps riskier projects attract debt financing at lower rates.	Value of loan guarantee depends on initial risk, but U.S. studies show a modest contribution to reducing LCOE.[128]	International Finance Corporation, Ex-Im Banks, U.S. DOE.
Sales or Property Tax Reduction/Waiver	Government or development banks make finance available at below-commercial terms. Sometimes paired with grants.	Can reduce LCOE by more than 1 cent/kWh.[129]	Arizona – Sales tax exemption for CST devices.
Concessionary Finance	Government or development banks make finance available at below-commercial terms. Sometimes paired with grants	Cost reduction helps CST compete with fossil fuels.	African Development Bank loans of €136 million to Morocco CST plant.[130]
Lower Import Tariffs	Governments reduce the import duties on parts and equipment used in renewable energy production facilities. Utilized in the early stage of technology development, before domestic manufacturing capacity exists.	Helpful for competing with coal because CST plant components are often imported, while coal plant equipment is widely manufactured.	China: 82 percent tariff reduction on imported wind parts, 65 percent tariff reduction on imported turbines.[131]
Export Credit	Government-owned export credit agencies provide loan guarantees to either domestic exporters of solar technology or to their importing customers. U.S. exporters benefit from the new 15-year repayment terms available from Ex-Im Bank to support U.S. exports to renewable energy, water, and hydroelectric power projects.[132]	Reduces currency risk that tends to handicap CST (imported plant components) but not coal (whose components are widely manufactured). Underwriting of loans by exporting-country governments reduces counterparty and foreign exchange risk.	PowerLight Corporation will export equipment for a 1-MW solar power project in Gwangju, Korea, with a medium-term loan guarantee from U.S. Ex-Im Bank.[133]
R&D Support	Public and private-sector R&D support can help drive more rapid technological improvement and technology breakthroughs.	Technological advancement that lowers costs for storage and heliostats can help CST compete better with coal.	U.S. DOE-funded R&D partnerships.

TABLE 7. **"Pull" Policy Options**

Type of Policy	Description	Pros or Cons for Strategic Displacement of Coal	Example of Use
Carbon Price	Carbon taxes or cap-and-trade systems impose a price on CO_2 emissions, making carbon-emitting power sources relatively more expensive. There are numerous ways to structure these mechanisms, which are outside the scope of this report.	Strongest policy pull for CST, though impact depends on level of carbon price. At current cost of CST, a carbon price of $80-115 would close the gap with coal, and this "switch price" would decrease as CST costs come down.	The EU emissions trading scheme (ETS) imposes a carbon price through cap-and-trade.
Carbon Offset Mechanism	When cap-and-trade mechanisms include provisions for offsets, this creates a market pull for projects that can deliver tons of GHG reductions. Projects can apply to the UNFCCC Clean Development Mechanism (CDM) and receive payment for every ton of CO_2 reduced by a project over its lifetime.	Offsets do not handicap coal, but under the Clean Development Mechanism they can be used to subsidize CST deployment in developing countries. Because they are paid per ton of $CO_{\neg 2}$ reduced, offsets are a strong incentive to build CST in coal-heavy grids. Overall, a larger allowance of offsets in a cap-and-trade scheme would reduce the carbon price, so may lessen the incentive for CST deployment in the region under the cap.	Certified Emissions Reductions (CERs) will be issued to support a program installing solar thermal hot water heaters on homes in South Africa (projects currently applying to the CDM).[134]
Renewable Portfolio Standard (RPS)	Mandates that a given percentage of power in a year is generated by renewable sources. Renewable Energy Credits (RECs), which represent the environmental attributes of energy generated from renewable sources, are issued for each unit of energy produced so utilities can demonstrate compliance. Some states have a solar "carve out", or a percentage set aside that must come specifically from solar.	RPS creates a market pull, and CST competes with other renewable energy technologies to fill it. An RPS does not ensure that coal is displaced; this depends on RPS design, demand curves, and relative viability of RE technologies in the given region.	Value of REC depends on state RPS design and trading price. Issued per MWh. Nevada has a 5 percent solar set aside.[135]
Level playing field	Removing support for coal-fired power can have a significant impact leveling the playing field for CST.	Would create a market pull for CST where coal subsidies have maintained generation from an otherwise uneconomical choice. The gap might be filled partially by CST and other technologies, depending on the load profile. Many coal plants in the U.S. are still economical only because they were grandfathered into the Clean Air Act and do not have to meet its standards if they do not trigger a New Source Review.	IEA estimated that the weighted average of consumption subsidies for coal in 20 non-OECD countries was 12 percent of reference energy price in 2005.[136]

Source: *WRI, and as noted in text*

Policy Experience to Date

The current CST industry has been and continues to be shaped by the policy framework(s) in which it operates. The most substantial policy experience to date has been in Spain and the U.S., where policies including feed-in tariffs, investment tax credits, and renewable portfolio standards, as well as various R&D support schemes have been applied.

Research and Development

Advanced research and development efforts on concentrating solar thermal power began in the late 1970s. Early research, both in the U.S. and in Europe, focused on improving performance and cost competitiveness.

United States

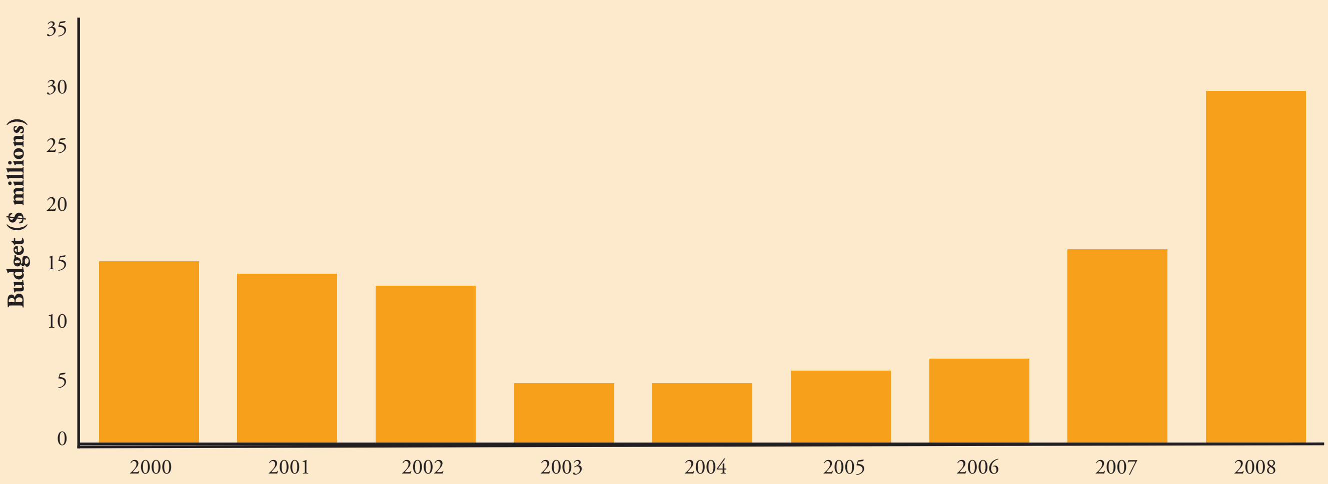
In the 1980s and 1990s, the U.S. DOE invested in large-scale demonstration plants to prove the feasibility of CST and research went into reducing the cost of solar reflectors and their support structures. For example, DOE projects evaluated new concentrator designs, explored replacing glass reflectors with polymer films, and improved the cost and durability of glass reflectors.[137] As a result, CST structures are becoming stronger, lighter, and less expensive.

However, between 2003 and 2006, federal support for solar thermal technologies decreased compared to earlier levels (see Figure 16). According to DOE, CST budgets were scaled back largely in response to a report by the National Academy of Sciences Review Panel highlighting the inability of CST to compete with incumbent power-generating technologies.[138] The report suggested that these systems would never reach forecasted deployment levels or become competitive because costs were too high. The report also noted that, at that time, there was little commercial support for CST compared to other technologies.

Recently, however, policies supporting low-carbon technology deployment, such as state renewable portfolio standards, have renewed commercial interest in CST. State and commercial interest in projects such as the Nevada Solar One plant have provided further impetus for DOE and Congress to reexamine DOE's CST subprogram. In 2006, DOE revived the subprogram, launching a 5-year strategy to commercialize CST through coordinated industry R&D and a focus on scaling deployment in the Southwest. With increased resources, DOE was able to reinstate its competitive proposal process, offering research and development contracts to industry partners.

DOE is now focused on a new goal for CST: providing baseload power at a competitive cost by 2020. To reach this target DOE estimates that solar thermal projects would require 12-17 hours of low-cost storage.[139] Planning for an increased research effort on storage began in 2008 and DOE announced up to $67.6 million in funding for 15 concentrated solar research projects. The 15 new projects will focus on developing lower-cost storage for CST and reducing the cost of CST with and without storage.[140]

FIGURE 16. DOE CST Budget, 2000-2008



Source: *U.S. Department of Energy*

Europe

Early R&D efforts in Europe also focused on improving performance and cost of CST, particularly parabolic trough collectors. Efforts were also made to develop solar receivers for central tower systems and solar-hybrid systems, and to reduce the costs of new and innovative components and systems. For example, the European Commission reports that it awarded €25 million of R&D funds under the EU Research Framework Programs (FP5 and FP6) for research on topics like components, storage, and solar–hybrid cogeneration.[141] Furthermore, the European Commission estimates that public investment has also attracted several hundred million Euros of private capital, or about 10 Euros for each Euro of public funding.[142]

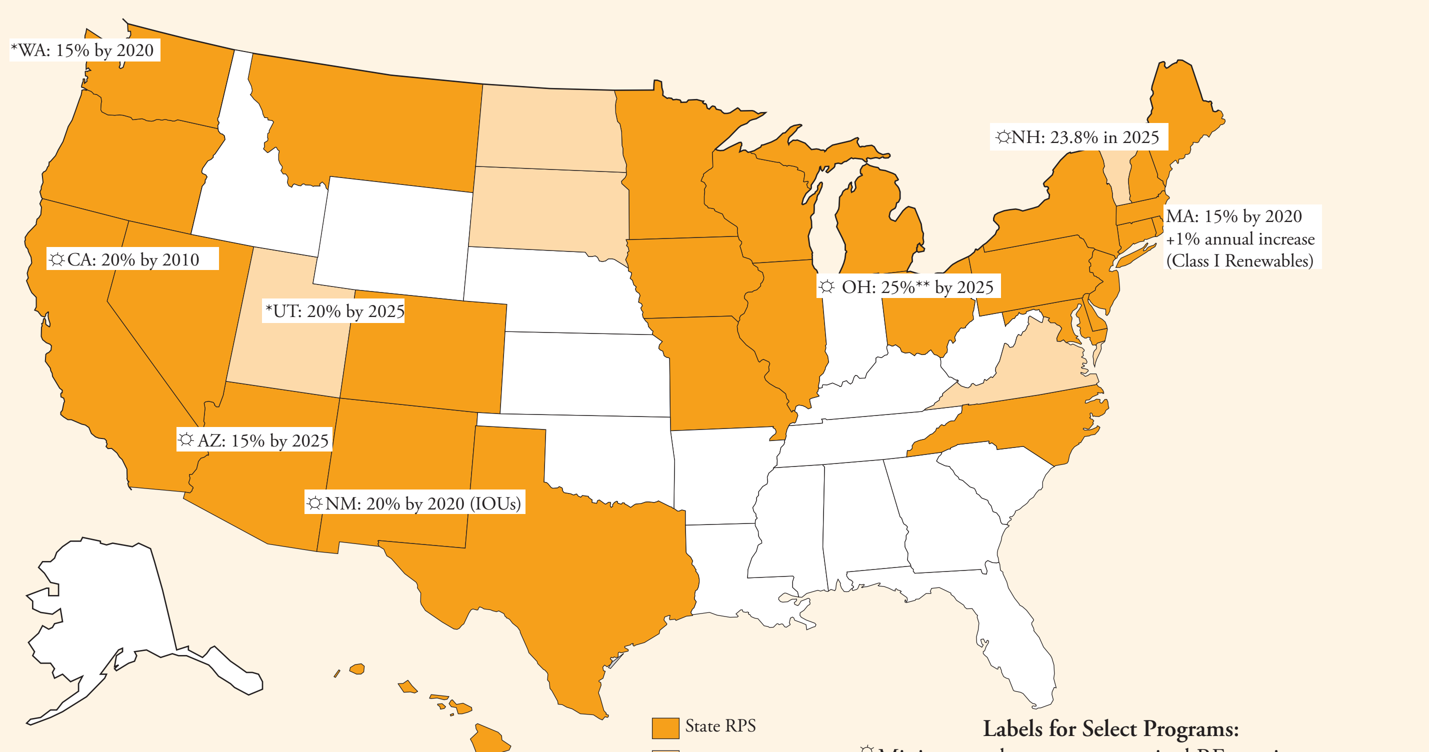
The EU has also backed various demonstration efforts. For example, under the Framework Programs for Research, Technological Development, and Demonstration, the European Commission invested €15 million in three demonstration projects.[143] These projects include the PS10 (11 MW), Andasol (50 MW), and Solar Tres (15 MW) projects in Spain. The stated aim of these investments is to validate full-scale application of different technological approaches, including power tower and thermal storage, under different market conditions.

Deployment

During the 1980s, the first commercial solar thermal projects were constructed in California as part of the Solar Energy Generating Systems (SEGS) project. These plants were built because of favorable power purchase agreements and tax incentives (35 percent in 1984-1986 to 10 percent in 1989).[144] During the development of the first nine SEGS plants, the technology evolved and improved. For example, working temperatures of the heat transfer fluid increased from about 300˚C to 400˚C from the first SEGS plant to the final plant.[145] In addition, the SEGS III-VII plants at Kramer Junction achieved a 37 percent reduction in O&M costs between 1992 and 1997.[146] Although these plants were improving the technology, when the incentives were terminated, construction of new solar thermal plants stopped and learning stalled.

More recently, many countries have implemented aggressive deployment policies aimed at achieving greater penetration of renewables into the marketplace, and many have included policies for CST in particular. Spain has used feed-in tariffs, while the U.S. has used renewable portfolio standards and an investment tax credit. While both policies incentivize deployment by rewarding CST developers, there are important differences between the two policies and the impact they have had on the market.

FIGURE 17. Renewable Portfolio Standards/Goals in the U.S. (April 2009)



Source: *Database of State Incentives for Renewables and Efficiency*

A renewable portfolio standard (RPS) aims to ensure a market for the power produced by renewable energy providers, mandating a target and letting the market decide what technologies are deployed. As of April 2009, 27 states and the District of Columbia have implemented RPS policies, and six additional states have set non-binding renewable energy goals (see Figure 17). These mandates cover almost half of the retail load in the United States. Nevada, Arizona, Colorado, and New Mexico have all recognized the particular benefits of solar and are promoting it through renewable portfolio standards with a specific requirement for solar (a solar "carve out") of between 1-4 percent of total generation. At the federal level, Congress has considered RPS provisions in energy legislation several times, but every attempt to date has failed on opposition from one chamber or the other.

These portfolio standards, particularly where they have carve-outs, have had a significant impact on the market for CST, pushing utilities and power providers to think beyond the traditional power generation sources and consider CST. Some Southwest utilities cite state RPSs as a driver of their interest in CST, saying that CST provides more valuable, firm power than other renewables and is attractive for the ability of CST with storage to meet peak demand.[147] Clearly, RPS policies have served to introduce CST earlier than otherwise might have happened and to educate both utilities and state regulators on its relative merits.[148]

The details of RPS policy design and implementation have considerable impact on the makeup of the resulting renewable portfolios, and on whether any coal-fired generation is displaced. An RPS typically specifies the percentage of total generation to come from renewables, but it can also specify the percentage of installed capacity (MW) or the percentage of kWh at a given demand period (e.g., percent of peak load). Lessons from California's RPS design show that if utilities are allowed to differentiate in contract price between those projects with higher capacity or environmental value, the social and environmental benefits of the RPS can be increased (see Box 7). It important, in designing RPS policies, to identify the specific goals behind the desire to promote renewables; careful analysis of the likely compliance portfolios can help ensure that the policy design will help meet those goals.

BOX 7. The Market Price Referent

The California Public Utilities Commission (CPUC) sets the Market Price Referent (MPR), its judgment of a "reasonable" price for a long-term contract. The MPR is the price at which utilities can contract renewable energy projects to meet the RPS. It is based on the LCOE of a new NGCC plant, a proxy for "business as usual" (BAU) technology. If a utility wishes to contract for renewable power at a price higher than the MPR, it must seek special CPUC approval and apply for state funding to offset the cost.[149] California is thus far the only state with an MPR system, but the experience to date has already generated some important lessons that are particularly relevant for CST development.

Renewable energy support policies should target the specific attributes of renewables that policymakers are seeking to exploit. If emissions reduction is the ultimate goal, policies to establish a "reasonable" price for renewable power must take into account the societal costs of existing and BAU technologies. In 2007, the CPUC started including a carbon price in costing out its proxy NGCC plant. However, by pegging the price of renewable energy to the assumed price of new-build NGCC generation, the MPR does not account for the societal benefit accrued when renewables displace existing capacity at times when the plants on the margin are inefficient or dirty. For instance, CST is ideal for displacing natural gas peakers, which are generally inefficient and therefore emit more GHGs, SOx, and NOx than new NGCC plants. Even some shoulder capacity in California is more GHG-intensive than the MPR's proxy NGCC turbines. Wind, on the other hand, often generates at night, and so in California it tends to displace nuclear, which is a relatively cleaner power source than the generation CST would displace during the day.[150] The MPR does not let utilities reward CST's higher displacement benefit via a higher price in a renewable energy contract.

Moreover, the MPR currently does not allow utilities to pay more for renewable generation contracts with more reliable capacity. The MPR used to reward the value of firm capacity, but it has been modified to exclude this provision. As such, power from CST plants with and without storage is valued at the same price. Policymakers seeking maximum emissions reductions from renewable energy deployment should design policies that reward firm capacity explicitly, as this capacity would enable greater baseload displacement.[151]

The MPR's structure prices all renewables equally, when in fact, based on their different generation profiles, they displace different fuels and thus have varied emissions savings. If the MPR priced renewable energy options based on the emissions they displace, CST would have a competitive advantage over many others.

Despite the increased interest in CST spurred by state RPS policies, however, the CST investments seen today would not likely go forward without the additional push from the Investment Tax Credit (ITC). The ITC subsidizes upfront capital costs by allowing a tax credit equal to 30 percent of the initial investment in the plant when it begins operation. The credit is made against the income tax liability of the plant owners, not the project itself (see Box 8). This is intended to improve project economics and ease financing. Whereas only 20 percent of a fossil fuel plant's lifetime costs are associated with construction (the majority of the cost comes from the purchase of fuel), 80 percent of the costs of a CST plant are related to the plant's construction.[152] While an ITC helps reduce the impact of high upfront capital costs, it does little to steer investment in solar power toward the most efficient and up-to-date technology, given the significant lead time required to plan, site, and construct a CST plant.[153]

The United States first offered an Investment Tax Credit for solar power with passage of the Energy Policy Act of 2005. (Between 1992 and 2005, solar power projects were eligible for the Production Tax Credit (PTC) of 1.5¢/kWh, adjusted for inflation.) The ITC, renewed for 8 years in October 2008, offers a 30 percent tax credit to solar projects. The most notable change in the renewal is that public utilities, which were previously ineligible, are now allowed to claim the credit.[154] Thanks in large part to this important subsidy, the CST industry has been growing quickly now, compared to the last 20 years of relative stagnation. However, it is not yet competitive without policy support.

Spain's primary CST support policy is the feed-in tariff (FIT). FITs are payments made by grid operators/utilities to renewable energy generators for the energy they supply to the grid. Grid operators are legally obligated to enter into long-term contracts (10-25 years) under which they will pay a fixed amount—above the average wholesale energy price—for each unit of renewable energy produced. Renewable energy generators are guaranteed access to the grid as well as constant demand for the energy they provide. Setting the tariff amount high enough to attract investment is critical, and this amount is calculated based on the production costs.

Spain was the first country to introduce a FIT for CST in 2002. The original FIT offered a rate of €0.12/kWh for electricity produced at CST plants with up to 50 MW of capacity. Spain increased the FIT to €0.18/kWh in 2004 and guaranteed this rate for 25 years, with annual adjustment for increases in average electricity prices. In addition, a premium was added for the first 200 MW of solar thermal power installed. This meant that for the first 200 MW of CST

BOX 8. The ITC & Structuring Finance For CST Projects

The Investment Tax Credit (ITC) is structured such that it can be applied to the income tax liability of a CST plant's owners, not just the tax on the plant's income. Since 30 percent of a $1-billion capital investment (or more) will far exceed the developer's tax liability, a tax equity partner—investors with large balance sheets and tax appetites—must be brought in to invest in the plant to monetize the developer's tax benefits. To date, tax equity providers interested in bankrolling the ITC for solar or geothermal have been limited to large investment banks and a few insurance companies. These tax equity partnership arrangements are an important part of renewable energy project finance. Since tax credit-based revenues are not high risk, the return on equity (ROE) expected has been fairly low (7-9 percent for some plants[155]), lowering the cost of finance and thus the project. Moreover, project construction loans cannot be procured until the developer can demonstrate that tax equity is secured.

The current financial crisis highlights the potential problems with relying on a tax credit incentive to make a CST project (or industry) financially viable. These projects are always somewhat exposed to downturns in the capital markets they depend on, far more so than fossil fuel plants, given the greater upfront capital requirements for CST. However, the ITC structure significantly narrows the pool of potential investors to the large investment banks who have enough tax appetite and experience or familiarity with the relevant tax rules. It also limits the pool to U.S. banks. Thus, the CST industry is overly dependent on a relatively small number of institutions, some of which have failed suddenly, and the rest of which now have reduced capital supply.

The health of an industry with high capital requirements will always be tied to the health of the financial markets and banks. However, the structure of incentives which are offered to renewables can either mitigate or exacerbate this exposure and the risks and difficulties of financing. A project with a feed-in tariff still requires loans, but it has a relatively more attractive and stable investment profile during financial turmoil and can access capital from a broader range of sources. The ITC renewal, by allowing equity investment and tax off-take by utilities with a very stable tax base, has potentially opened the door to a badly needed source of financing for CST. California has also designed an innovative tax bond structure around the ITC, allowing certain property owners to essentially borrow capital at zero percent interest against the forthcoming tax credits due to the project.[156]

constructed the total tariff rate was €0.21/kWh, resulting in a race to install CST capacity. In 2007, Spain again increased the tariff rate to €0.27/kWh.[157] Several other countries have launched renewables support policies that target CST within an RPS or directly with a FIT. In 2006 Israel published new Feed-In Incentives for Solar-Driven IPPs. Solar installations or the solar energy output of hybrid systems are eligible for a FIT of US$0.163.[158]

In 2004, Algeria established a renewables target of 5 percent of total generation in 2010. The law includes several complementary policies, mandating that grid operators connect renewable power plants to the grid and establishing technology-specific tariffs above the market price of power. Algeria's policy has led to the successful tendering of the 150-MW hybrid solar-gas plant at Hassi R'mel. The plant is due to go into operation in 2009 and has a 25-MW solar energy capacity with a parabolic trough design.[159] In addition, Algeria and Germany have signed a joint research agenda with the goal of scaling up CST technology in Algeria. German researchers will have access to data from the Hassi R'mel plant when operating, and they will assess how to optimize collector efficiency, improve component manufacturing, and develop thermal storage.[160]

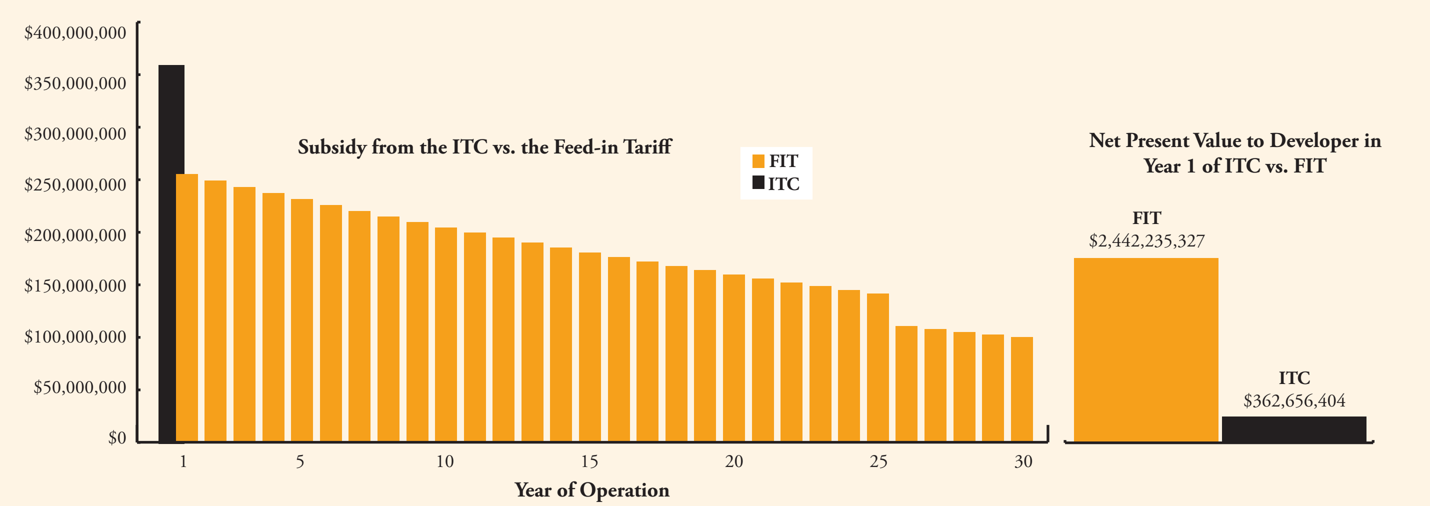
India's first National Action Plan on Climate Change (2008) also includes provisions for solar energy. It establishes a National Solar Mission to promote the development and deployment of solar, including international, collaborative R&D on storage and a 1,000-MW goal for CST deployment.[161]

Policy Lessons: Comparing the Investment Tax Credit and the Feed-in Tariff

Spain's FIT and the U.S.'s ITC have major differences in the level and type of support they provide. The ITC generates an upfront subsidy of significant value, but the value is nowhere near that of the FIT. Figure 18 compares the value of the subsidies as they would apply to the 200-MW base case described in Section 2.[162] It is important to note that the Spanish FIT is made available only to the first 500 MW built in Spain at the level shown; once those have been installed it will be revised down.[163] This creates competition between developers in Spain to develop projects quickly.

In addition to the significant difference in value, the structural difference between the FIT and ITC provide different kinds of incentives to project developers. The FIT has aspects of both "push" and "pull" policies: it pulls the technology by guaranteeing a market but also pushes the technology into the market by subsidizing it with a tariff above the market price for power. The particular design of the FIT in Spain, where plants are capped at 50 MW in size to be eligible, means that the policy pushes storage especially hard. The 50-MW cap reduces economies of scale, but it makes storage the only choice for developers seeking to increase generation from the plant, in effect "increasing" the size of the plant while keeping it under the cap.

FIGURE 18. Comparing ITC and FIT: Annual Subsidy Amount over Life of Plant and Net Present Value to the Project Developer



Calculated for a 200 MW trough plant in Arizona for illustration. Value of the FIT per MWh is calculated as the difference between the FIT price and the LCOE of the plant. Value is then multiplied by the generation in the given year and the annual cash flows arecorrected for inflation in the first figure, and discounted at the discount rate of the developer in the model (10.7% in the second). The FIT premium in the first 25 years is 27 euro cents/Kwh, and is 21.6 cents thereafter.

The FIT ensures a market for CST electricity by requiring Spanish utilities to off-take it at any time of day, at a fixed price. This makes storage much more valuable, as the plant is guaranteed a buyer at any hour without having to compete with cheap generation (i.e., at night). For example, the FIT in Spain has spurred development of at least three trough plants (the Andasol projects), and Solar Tres, which will install 15 hours or storage and expects to achieve a capacity factor above 70 percent.[164] Under a FIT scheme, the value of a kWh produced is the same whether produced at 3:00 p.m. or 2:00 a.m., and in Spain it is fixed high enough to cover the additional cost of storage, even if it is fairly high. Finally, because a project will profit from the difference between the FIT price and its actual production cost, a FIT provides an incentive to innovate and reduce capital cost that an ITC does not.

An ITC can help developers pay for a plant with storage, but the revenues from off-peak electricity will still be lower. It makes the LCOE cheaper but does not ensure a market for the power, and utilities may choose not to contract it for any number of reasons. A production-based incentive such as a production tax credit could incentivize storage by augmenting revenues during off peak times, but it does not guarantee a market for the power and would still reflect a differential in off-peak times. Finally, tax-based incentives present certain challenges that can reduce their efficacy (see Box 8). At best, these challenges mean bigger paychecks for the tax lawyers who must figure out how to structure the finance and ownership of projects to monetize the tax benefits. At worst, the incentive structure makes the CST industry more exposed to risks and downturns in the capital markets than it would be otherwise.

Closing the Gap: Additional Policy Support is Still Needed

In-country deployment in developed countries

In developed markets, renewable energy incentives and market dynamics are promoting CST deployment. However, the pace of this deployment can be accelerated through implementation of key push and pull policies to bring down the technology's cost while increasing the cost of its fossil fuel-based competition.

Accelerate Learning

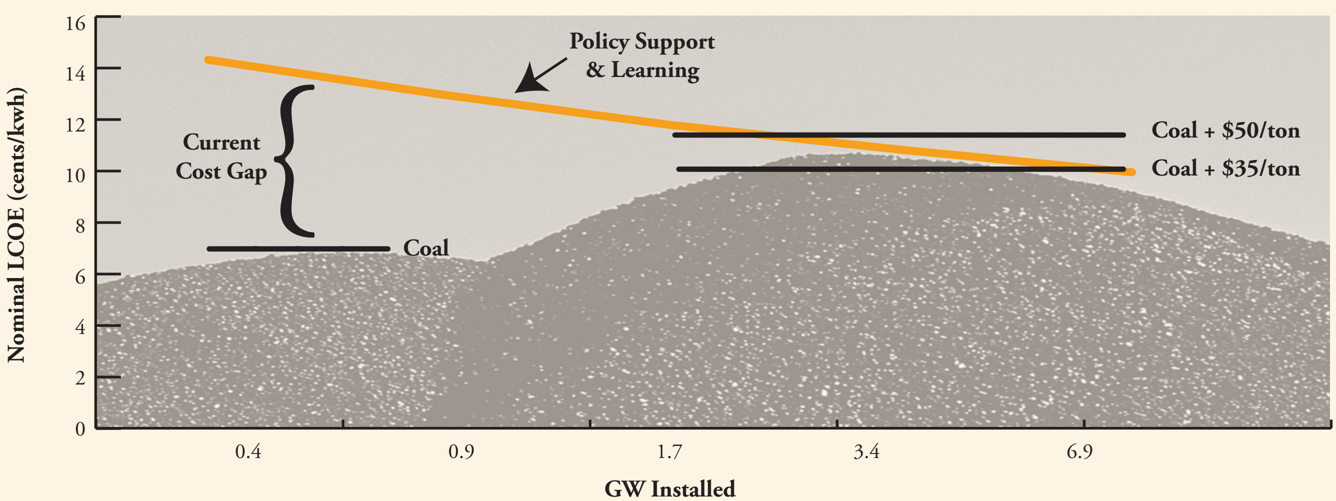
By encouraging sustained investment in CST to grow the market, policy can help drive cost reductions through learning (see Box 3, page 17). Without temporary subsidies to help create a market for CST, companies may not have the opportunity to realize these cost reductions. Figure 8 on page 17 depicts the potential for cost reductions possible through deployment given various expectations of learning rates. Sustained investment in the CST industry will only occur if companies recognize a market opportunity on par with the risks they take, whether investing in research, a pilot project, a 250-MW plant, or a factory to produce reflective mirrors. Therefore, the strongest policy recommendation is a principle rather than a mechanism: support policies for CST must be enacted over a timeframe long enough to create a stable market for the products developed in each part of the value chain. Sustained policy support for CST can bring the costs down over time as component producers, project developers, utilities, and finance institutions learn from experience and become increasingly comfortable with the technology.

TABLE 8. **Estimated Carbon Switching Price**

Assumptions	Coal	Trough	CLFR
Carbon Intensity (tons/MWh)	1.00	0.00	0.00
LCOE (¢/kWh):			
Real	6.26	15.36	12.61
Nominal	7.91	19.42	15.94
Real Switching Charge (\$/ton CO_2)		**91.00**	**63.50**
Nominal Switching Charge (\$/ton CO_2)		**115.10**	**80.30**

Source: World Resources Institute

FIGURE 19. Future Carbon Switch Price



Source: *World Resources Institute*

Price on Carbon

The types of cost reductions described above may still not bring CST down to a level necessary to compete effectively in many power markets. Although subsidies could continue to cover the gap between CST and coal-fired power, extended subsidization may not be politically feasible. Another option to decrease the cost gap between solar and coal is increasing the cost of coal-fired electricity through a price on carbon emissions. Cap-and-trade, like the European Union Emissions Trading Scheme (EU ETS), is currently the most likely mechanism for putting a price on carbon in the U.S.

To bridge the current cost gap between coal-fired electricity and concentrating solar thermal power, coal-fired generators would need to incur a significant carbon penalty. For parabolic trough technologies to become economic with coal-fired power we estimate a carbon charge of $115/ton of CO_2 would be necessary. For CLFR technologies, we estimate, based on industry data, that a lower—although still significant—carbon charge of $80.30/ton would be necessary to level the economics of solar and coal-fired electricity.

While significant, these carbon charges are not outside the realm of possibility for a carbon price trajectory. In 2008, the U.S. Congress considered the Lieberman-Warner Climate Security Act, a bill proposing a cap-and-trade system to limit carbon dioxide emissions. Although the bill failed to make it through Congress, it is an indication of how U.S. climate policy may evolve. This bill would have imposed an initial carbon price between $29 and $40/ton CO_2 at the start of the cap-and-trade program.[165]

This initial price would steadily increase until 2050 when carbon prices could reach $159 - 220/ton CO_2. Other analyses, such as those performed by the Massachusetts Institute of Technology, suggest a carbon price trajectory starting between $48/ton of CO_2 in 2015 and escalating to $189/ton CO_2 in 2050.[166] On the international front, allowances under the EU ETS trade at roughly €11-12/ton ($15-16/ton), and prices for Certified Emission Reduction (CER) credits currently being paid to Clean Development Mechanism projects are between €10-17, or about US$13-23.[167]

Figure 19 illustrates how the gap may be closed between the cost of coal (without CCS) and CST. If anticipated cost reductions from learning are achieved, the switch price between coal and CST will shrink significantly between now and the future when some of the planned 9,000 MW have been built. Furthermore, the potential for other cost reduction by more advanced technology is quite real but is impossible to illustrate here. Even at the current LCOE of troughs with the 30 percent ITC, the switch price is quite close to that which would be expected in the early years of a federal cap-and-trade program. If costs were to be reduced, future (cheaper) CST plants would enjoy a distinct advantage as the cost of carbon is expected to rise far higher than the switch price. The LCOE analysis is not performed for projects in developing countries, which would not receive the ITC as shown below, but a combination of CDM or other international support and domestic policies could indeed close the gap.

Global deployment: developing countries

It is unlikely in the near term that a carbon price will be imposed in developing countries. However, as discussed above, mechanisms like the CDM under the UNFCCC make marginal abatement costs (essentially a carbon price) a relevant consideration for international deployment in developing countries as well.

While carbon pricing may be a relevant policy tool to accelerate CST deployment in developing countries, the concept of technology cost reductions through learning may be less applicable in developing countries than in the developed world. On the one hand, deployment in developing countries could reduce some costs, particularly construction or component production costs due to lower labor costs, for instance. As well, country-specific learning may be needed sooner or later to deploy the technology in the country. On the other hand, by deploying early-state technologies in developing countries, project developers face a significantly increased risk premium, which risks delaying technology deployment if delays to initial projects contribute to a sense of the technology as risky or unreliable. Future research needs to explore the balance between these two effects to understand the extent to which technology deployment in developed countries should contribute to cost-reductions through anticipated learning.

In the meantime, however, transferring CST technology to developing countries is critically important for emissions reductions globally. Progress has been slow, with projects in developing countries encountering significant barriers (see Box 6). Studies evaluating the experience to date with deploying CST in developing countries have reached several important conclusions:

- Efforts to deploy new technologies internationally must take into account the full range of market barriers, including transactional, informational, and capacity barriers, rather than simply focusing on technological and cost barriers.[168]
- Supportive regulatory environments are more important to successful technology deployment than cost buy-downs.[169] Subsidized finance alone is not enough to promote the introduction of new technologies.[170]
- International technology deployment efforts will not succeed if they are not country-driven, lack the engagement of the host country, or do not bring benefits or synergies with local development goals.[171]
- Developing countries cannot be expected to deploy new technologies without interest or investment in the technology from the rest of the world. A simultaneous global push for CST technology deployment is necessary for successful developing country deployment.[172]

Despite these challenges, there are emerging opportunities in the international policy arena for developing countries to secure developed country support for climate-friendly technology deployment. It is worth exploring how these opportunities could apply to CST specifically.

In 2007, the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Bali Action Plan (BAP). This plan charts a path to a new international climate agreement that will create a space for developing countries to take nationally appropriate actions that advance their national development goals while addressing global climate change mitigation priorities. The BAP also stipulates that developed countries, in addition to committing to domestic GHG reductions, will provide technology, finance, and capacity-building support for these developing country mitigation actions.[173]

In UNFCCC negotiations around technology deployment, the importance of a country's "enabling environment" is increasingly recognized,[174] as both developed and developing countries have emphasized the need to make investments in clean energy technologies more appealing to private investors.[175] Under the framework emerging from the latest negotiations, countries could come forward with and receive support for nationally developed policies and measures aimed at building an environment more conducive to attracting private investment in clean energy technologies, including specific support policies for renewables.

It remains unclear how directly the developed country support will be matched to the developing country actions it is intended to support. If support is directly linked to proposed mitigation actions, however, developed country support for CST-related mitigation actions could include:

- capacity-building for successful implementation of national renewable energy policy or plans, including specific policy support for CST;
- financial support for the full incremental cost of renewable or CST support policies (e.g., feed-in tariffs);
- technical support in CST site selection, including financing of required on-site monitoring of sufficient DNI prior to project implementation;
- technical and/or financial support for building the necessary transmission lines to link CST projects to the grid;
- capacity-building support, including training on CST installation and operation as well as training for grid operators; and
- a commitment to ongoing support for CST deployment within industrialized countries' policy frameworks to ensure continued commercial interest in the technology.

This approach would address many of the shortcomings experienced with international support for CST deployment to date. The framework would enable a country-driven approach to technology deployment, where developing countries assess their needs and suitable resources and can receive support from developed countries for proposing specific mitigation actions or projects as well as the more programmatic policy reforms needed to create stronger enabling environments for technology deployment. As the GEF experience demonstrates, financial support for technology deployment from multilateral institutions does not necessarily mean there will be a viable market for the technology beyond individual projects, so private sector actors may be less inclined to participate in the projects. However, domestic, country-driven support for CST, in the form of specific support policies such as a feed-in tariff, could signal ongoing interest in building a market for the technology, which would be more attractive to private investors and project developers in the long-run.

> ***Sustained policy support for CST can bring the costs down over time as component producers, project developers, utilities, and finance institutions learn from experience and become increasingly comfortable with the technology.***

SECTION V

Conclusion

There is clearly significant potential for concentrating solar thermal power to meet growing electricity demand while contributing significantly to climate change mitigation efforts by displacing carbon emissions from coal-fired generation. Policy support will be critical to achieving this displacement in the near term. Some policy interventions support CST generally, while some encourage storage, which gets CST closer to displacing coal. These policies are important as they drive CST cost reductions and can even yield significant CO_2 reductions by displacing inefficient natural gas plants on the margin. However, they are unlikely to enable significant displacement of coal emissions on their own. A price on carbon would enable a portfolio of renewable energy technologies to compete with coal directly, and CST with storage or CST integrated into this portfolio of renewable energy technologies could help displace baseload coal.

Utilities need to start taking a serious look at what such an integrated portfolio looks like, how to balance the technologies for the maximum emissions reduction, and how to deploy the necessary transmission infrastructure to serve demand. Significant improvements in key regions' electricity grids will also be required. For adopting CST in place of coal, utilities may have more options if they can use integrated planning and regionalization of power markets to their advantage to expand the portfolio of available renewable energy resources at their disposal. Domestic policies that support utilities' efforts to integrate renewables, including preferential pricing, mandates, and carbon prices can help. Investment in CST offers an exciting opportunity to begin the transformation of the power sector that climate change mitigation requires.

Appendix A: Financial Analysis Methodology

The cost comparison of power plants analyzed in this report is based on levelized cost of electricity (LCOE). Levelized cost of electricity is a financial analysis technique that summarizes the estimated lifetime costs of each power plant as an annualized cost per unit of electricity generation or kilowatt-hour. Comparing LCOEs is a good way to compare two types of plants that may have different lifetimes, upfront costs, and fuel costs. A generic cash flow model was used to calculate the LCOE of a coal plant, a trough plant with six hours of thermal storage, and a Compact Linear Fresnel Reflector plant.

To calculate the LCOE we used a generic cash flow model; the model was developed by the National Renewable Energy Laboratory (NREL) for use in conjunction with their Solar Advisor Model (SAM). SAM is a separate solar-specific application that models the costs and technical parameters of a given concentrating solar thermal power (CST) plant. SAM also uses a discounted cash flow analysis to calculate a LCOE representing the constant dollar electricity price required to recover all investment costs, including capital, operations, fuel, and financing costs. The LCOE generated by SAM and the pro-forma are identical because both models use an identical methodology. The model is available at https://www.nrel.gov/analysis/sam/download.html.

Key inputs, including capital costs, non-fuel operations and maintenance expenses, plant efficiency, plant utilization rates, and fuel prices were estimated based on a review of public reports and information on recent projects. Capital costs represent total plant costs including all equipment, materials, labor, engineering and construction management, and contingencies. Project contingencies were added to each technology to cover project uncertainty and the cost of any additional equipment that could result from detailed design. Project contingency was 6 percent for each case analyzed.[176] A fuel cost of $1.92/MMBtu (2008 dollars) was determined from the Energy Information Administration's *Annual Energy Outlook 2008*. This price represents an average price for delivered coal. Plant-specific inputs are listed in Table 9. The analysis also relied on the economic and financial assumptions found in Table 10.

For the coal plant estimate, capacity and capital costs are based on a study by the World Bank's Energy Sector Management Assistance Program, which analyzed equipment prices in the power sector. Operations and maintenance costs, heat rate, and fuel costs are based on the Energy Information Administration's *Annual Energy Outlook 2008*. EIA figures were adjusted to 2008 dollars using the Bureau of Labor Statistics CPI Calculator.

For the parabolic trough plant, capacity, capital costs, operations and maintenance, and capacity factor inputs were generated by SAM, using cost data gathered by NREL.[177] Cost data were used as provided in SAM and supplemented by an additional spreadsheet from Mark Mehos of NREL in order to model a 200-MW plant. The plant has a 200-MW net rated capacity, a solar multiple of 2.15, and six hours of thermal storage in a two-tank storage system with Solar Salt as a medium. It is located in Phoenix, Arizona.

For the CLFR plant all figures are based on Ausra cost estimates found in the Center for Global Development report on solar thermal power.[178]

TABLE 9. Plant Specific Inputs

Factor	Pulverized Coal	Trough (6hrs)
Capacity (MW)	500	200
Capacity Factor (%)	85%	40%
Capital ($/kW)	2, 290	6,044
Fixed O&M ($/kW)	29.11	50.00
Variable O&M ($/MWh)	4.85	0.71
Fuel ($/MMBtu)	1.92	0.00
Real LCOE (c/kWh)	**6.26**	**15.36**
Nominal LCOE (c/kWh)	**7.91**	**19.42**

Source: *NREL, Solar Advisor Model*

TABLE 10. Economic and Financial Assumptions

Major Economic Assumptions	
Analysis period	30 years
Inflation rate	2.50%
Real discount rate	8.00%
Plant startup date	2008
Major Financial Assumptions	
Depreciation	MACRS Mid-Quarter
Federal income tax	35%
State income tax	8%
Sales tax	7.75%
Insurance	0.50%
Capital Structure:	
Common Equity	40% (Cost = 15%)
Debt	60% (Cost = 8%)
PPA Escalator	0.6%
Minimum DSCR	1.00

Source: *NREL, Solar Advisor Model*

Appendix B: Emissions Projection Methodology

All emissions reduction calculations in this report are based on the Supplemental Data Tables from the Energy Information Administration's *Annual Energy Outlook 2008* and *International Energy Outlook 2008* reports. These reports forecast power sector statistics by region from 2006 to 2030. The 25-year period from 2006-2030 serves as the timeframe for emissions reduction analysis in this study.

This report analyzes potential CO_2 emissions reductions in the U.S. Southwest, the United States as a whole, India, China, and OECD Europe. For all country-level calculations, the AEO2008 and IEO2008 reports are broken down by country. The calculations for the U.S. are based on data from the AEO2008 report. The AEO2008 report presents power-sector statistics by North American Electric Reliability Corporation (NERC) sub-regions. For the purposes of this report, all statistical calculations for the southwestern U.S. include the California (CAMX), Arizona, New Mexico, Southern Nevada (AZNM), and Rocky Mountain Power Area (RMPA) sub-regions, as designated by NERC.

The AEO2008 and IEO2008 reports include projections for the CO_2 emissions from the power sector by fuel type; however, these figures encompass the CO_2 emissions from existing power plants as well as future plants. As this report concentrates on displacement of only *new* fossil fuel plants with CST, the authors have modeled the projected CO_2 emissions from power plants that will become operational after 2005.

Using the AEO2008 and IEO2008 data, WRI created a model that, by inputting projected new fossil fuel generating capacity, can output an estimate of the CO_2 emissions that will result from this additional generating capacity. First the model calculates the amount of new generating capacity of a given fuel type that is brought on-line in each of the 25 years. The AEO2008 and IEO2008 reports both forecast generating capacity (in gigawatts) by fuel type annually through 2030. The difference in the generating capacity of a given fuel type from one year to the next represents the new generating capacity of that fuel type brought on-line during that 12-month period.

Next, the model converts the new generating capacity for each year into net generation (measured in megawatt-hours) using the following equation:

Equation 1

New Generating Capacity x Hours per Year x Plant Capacity Factor = Net Annual Generation

At this stage of the model, all negative net annual generation values are replaced with zero. These negative values are assumed to represent the retirement of generating capacity that existed before 2006 rather than the retirement of newer generating capacity. Including the negative values in calculating the cumulative new generation over the entire 25-year period would, therefore, place a downward bias on the figure. For details on the assumptions made about plant capacity factors, please see the section below.

Once new generating capacity becomes operational, the authors assume that this new capacity will continue to generate a constant amount of electricity—thus emitting a constant amount of CO_2—in each successive year through 2030. Therefore, each annual net generation total is then compounded, meaning it contains both the net generation brought on-line that year as well as the sum of the annual totals from each of the previous years.

Finally, the compounded net generation for each year is converted into CO_2 emissions using the following equation:

Equation 2

Compounded Net Annual Generation x Fuel Emissions Factor = Annual CO_2 Emissions

Multiplying the net generation figure by an assumed emissions factor (measured in t CO_2/MWh) yields the total CO_2 emissions from generation in that year. Since generation powered by CST does not emit any CO_2, this figure represents the potential emissions reduction from displacing the given fuel in a given year. The sum of the 25 annual CO_2 emissions figures represents the total emissions and, therefore, potential emissions reduction from displacing a given fuel from 2006 through 2030. Details on the assumed emissions factors are provided below.

In the AEO2008 report, generating capacity is broken down into the following categories:

In this study, we assumed that coal plants include the Coal category, and that natural gas plants include the Oil and Natural Gas Steam, Combined Cycle, Combustion Turbine/Diesel, and Distributed Generation categories. All other categories are assumed to have zero emissions. For the southwestern and entire U.S. analyses, the business-as-usual emissions calculations are simply the sum of coal and natural gas emissions.

In the IEO2008 report, generating capacity is broken down into the following categories:

For fossil fuel plants in India, China, and OECD Europe, coal and natural gas plants correspond to the Coal-Fired and Natural-Gas-Fired categories respectively. For the purposes of this report, the Liquids-Fired category is assumed to have the attributes of oil-fired plants. Plants from the Nuclear and Hydroelectric categories are assumed to have zero CO_2 emissions. Therefore, business-as-usual emissions calculations for the India, China, and OECD Europe analyses are the sum of Liquids-Fired, Natural-Gas-Fired, and Coal-Fired plant emissions.

Capacity Factor Assumptions

To convert the forecast gigawatts of new generating capacity as provided in the AEO2008 and IEO2008 reports to net generation projections, assumptions must be made regarding a plant's capacity factor.

For U.S. domestic fossil fuel plants, our capacity factor assumptions are based on data from the Energy Information Administration's *Annual Electric Generator Report, 2006* (Form EIA-860). U.S. coal plants are assumed to have a capacity factor of 72.6 percent. For the purposes of this study, natural gas plants are divided into two categories: Combined Cycle plants have been deemed baseload/shoulder plants with a 38.3 percent capacity factor, while Oil and Natural Gas Steam, Combustion Turbine/Diesel, and Distributed Generation plants have been deemed peak-load plants with a 10.7 percent capacity factor.

For both the southwestern U.S. and United States calculations, we assumed that all CST plants have a capacity factor of 40 percent. This assumption is based on the capacity factor generated by NREL's Solar Advisor Model for the 200 MW CST plant located in Phoenix, Arizona, that is modeled in this report's power plant cost comparison.

For a full discussion of the CST plant modeled in this report, please see Appendix A. All domestic capacity factors are assumed to be constant throughout the 25-year period.

A single source documenting plant capacity factors by fuel type in India, China, and OECD Europe was not available. For fossil fuel plants in these regions, therefore, our capacity factor assumptions are based on the IEO2008 Supplemental Data Tables. The capacity factors were reverse-calculated with the net generation for a given fuel in a given country being divided by the maximum possible generation (Generating Capacity x Hours in a Year). The following table provides the capacity factors that were used in calculating international CO_2 emissions.

TABLE 11. International Capacity Factor Assumptions (%)

	China	India	OECD Europe
Coal	70.1	70.8	56.4
Natural Gas	36.5	26.2	48.3
Oil	35.5	36.4	15.5

Source: *EIA 2005*

All capacity factors are based on 2005 data from the IEO2008 report and assumed to be constant throughout the 25-year period. Concentrating solar thermal power plants in India, China, and OECD Europe are all assumed to have capacity factors of 40 percent throughout the entire 25-year period.

Emissions Factor Assumptions

The U.S. emissions factors used in this report are from the U.S. Environmental Protection Agency's Emissions & Generation Resource Integrated Database (eGRID). This study used eGRID2006, Version 2.1 with data for the year 2004. Emissions factors for the southwestern U.S. are taken from the Sub-Region Location-Based File tab of the eGRID2006 database. To match the sub-region breakdown in the AEO2008 report, the emissions factors for the AZNM and RMPA sub-regions have been combined into a weighted average.

Emissions factors for India, China, and OECD Europe are from the International Energy Agency's Data Services website (CO_2 Emissions from Fuel Combustion, 2004 data). All emissions factors in this report are assumed to be constant throughout the 25-year period.

Endnotes

1. International Energy Agency (IEA), *World Energy Outlook 2007* (Paris: IEA/OECD, 2007).
2. International Energy Agency (IEA), *Energy Technology Perspectives 2008* (Paris: IEA/OECD, 2008).
3. International Energy Agency (IEA), *Energy Technology Perspectives 2008* (Paris: IEA/OECD, 2008), p. 81.
4. International Energy Agency (IEA), *World Energy Outlook 2007* (Paris: IEA/OECD, 2007).
5. For a discussion on the challenges of deploying carbon capture and storage at a large scale see Fernando et al., *Capturing King Coal: Deploying Carbon Capture and Storage Systems in the U.S. at Scale* (Washington, DC: World Resources Institute, 2008).
6. Although it is often referred to as concentrating solar power (CSP), we use CST in this report, because CSP can also refer to Concentrating Photovoltaics.
7. Capacity factor of a power plant is the ratio of the actual output of the plant over a period of time to its potential output operating at rated capacity over that time. If the capacity factor is 30 percent, the plant produces electricity during *h* hours throughout the year, where *h = 30% (8760 hours) * rated maximum capacity.*
8. U.S. Department of Energy, National Energy Technology Laboratory, *Cost and Performance Baseline for Fossil Energy Plants* (Volume 1, DOE/NETL-2007/1281, 2007).
9. The CPUC methodology for determining the Market Price Referent involves assessing standard capacity factor for baseload and peaking plants. Capacity factor varies more for peaking plants than baseload, but the CPUC decided to use a 23.3 percent value as a default. California Public Utilities Commission, *Revised 2004 Market Price Referent (MPR) Staff Report* (2004). Online at: http://docs.cpuc.ca.gov/published/Rulings/43825.htm.
10. Figures include CO_2 emissions from combustion for heat and power in 2005; figures for coal-fired electricity were not available separately. Source: IEA Data Services, CO_2 Emissions from Fuel Combustion. Accessed September 17, 2008.
11. S. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science* (August 13, 2004, Volume 305). One Gigatonne is 1/25th of a wedge (25 gigatons). Source of assumptions is the Wedges Supporting Material document published in the Journal of Science. Assumptions are that 700 GW of coal capacity displaced by 2050 (generating 5400 TWh) equals a wedge, and that a wedge for natural gas is approximately double that capacity.
12. "Overview of Solar Thermal Technologies," Harvard Energy Journal Club (2007). Online at http://www.hcs.harvard.edu/~hejc/papers/Solar%20Jan07/solar_thermal_overview.pdf.
13. SolarPaces, *Solar Dish Engines*. Online at http://www.solarpaces.org/CSP_Technology/docs/solar_dish.pdf.
14. H. Price et al., *DOE Advanced Thermal Energy Storage Development Plan for Parabolic Trough Technology* - DRAFT (U.S. Department of Energy, 2007).
15. This depends on length of day in the region. This could be 11 hours for Arizona in the summer. See Patrick Dinkel, *APS Perspective on CSP*, SolarPaces (2008).
16. Peak load is the highest level of power demand in a day, and typically occurs around 5:00 p.m., though this depends on the region/utility's load profile.
17. CST dispatchability benefits from hybridization with gas, whether traditional natural gas or biogas. Its displacement potential would be enhanced by this sort of design, but integration with other renewables (on the grid, but not necessarily in the same plant) also has potential. The generation profile of wind power, for example, is somewhat inverse to that of CST, based on data from the CA ISO, 2002. See H. Price et al., *Advanced Thermal Energy Storage Development Plan*—DRAFT (2007), p. 26.
18. Levelized cost of electricity is a financial analysis technique that summarizes the estimated lifetime costs of each system as an annualized cost per unit of electricity generation or kilowatt-hour. These estimates should be taken as representative and are impacted by the inputs and assumptions surrounding the calculation.
19. Nate Blair, *The Solar Advisor Model and its Usage for the Solar America Initiative,* National Renewable Energy Laboratory, (March 13, 2008), Online at http://www.nrel.gov/analysis/seminar/archive.html.
20. National Renewable Energy Laboratory (NREL) website. Online at http://www.nrel.gov/csp/troughnet/power_plant_systems.html#hybrid.
21. H. Price et al., *DOE Advanced Thermal Energy Storage Development Plan for Parabolic Trough Technology*- DRAFT (U.S. Department of Energy, 2007), p. 9.
22. Bruce Kelly, Personal Communication.
23. Technically, a plant could be run 24-7 even in the winter by running the turbine at partial capacity, but this would be inefficient and uneconomical.
24. This is demonstrated by using NREL's Solar Advisor Model, which models capacity factors for plants for a given technological specification, given number of hours of storage, and solar multiple. The technological specifications for "today's" technology are: 391 degrees Celsius solar field outlet temperature, two-tank storage, solar salt storage, but synthetic HTF (VP-1).
25. J. Ignacio Ortega et al., *Central Receiver System (CRS) Solar Power Plant Using Molten Salt as Heat Transfer Fluid* (Sevilla, Spain: 2006). Online at www.sener.es/EPORTAL_DOCS/GENERAL/FILE-cwa0fcc36424ab41b7bf04/**S**OLAR-TRES.pdf.Note that this study states that the Solar Tres plant could be run as per the schedule/capacity factor described in the text, given the amount of storage/hybridization planned, but the plant may not ultimately dispatch on said schedule.
26. The ratio of thermal energy collected in the field to the energy that the turbine can turn into electricity at any given moment is known as the solar multiple. Plants without storage typically are built with a lower solar multiple.
27. Pumping HTF around the larger field and preheating it in the morning requires more power, and HTF loses heat and pressure as it travels longer distances to the power block.
28. As highlighted earlier, the output of a solar thermal plant is a factor of direct normal irradiation, solar multiple, and integration of thermal storage. Capacity factor estimated based on generation quoted in http://news.cnet.com/Solar-thermal-energy-making-a-comeback/2100-11392_3-6189468.html.
29. Energy Information Administration (EIA), *Assumptions to the Annual Energy Outlook 2007* (Washington, DC: EIA, 2007). Online at http://www.eia.doe.gov/oiaf/archive/aeo07/assumption/index.html.
30. With more geographically distributed portfolios of wind generation, it is expected to exhibit less intermittency, but this is still an interesting option for the nearer term.
31. Van Atten et al., *Benchmarking Air Emissions of the 100 Larges Electric Power Producers in the United States* (Ceres, the Natural Resources Defense Council (NRDC), Public Service Enterprise Group (PSEG), and PG&E Corporation, 2008).
32. H. Price et al., *DOE Advanced Thermal Energy Storage Development Plan for Parabolic Trough Technology* - DRAFT (U.S. Department of Energy, 2007).
33. H. Price et al., *DOE Advanced Thermal Energy Storage Development Plan for Parabolic Trough Technology* - DRAFT (U.S. Department of Energy, 2007).
34. H. Price et al., *DOE Advanced Thermal Energy Storage Development Plan for Parabolic Trough Technology* - DRAFT (U.S. Department of Energy, 2007), p. 42.
35. Terry Murphy, Solar Reserve, Personal Communication, December 23, 2008.

36. D. Mills and Robert Morgan, *STE as a Primary Replacement for Coal and Oil in U.S. Generation and Transport* (2008).
37. U.S. Department of Energy (DOE), *Assessment of Potential Impact of Concentrating Solar Power for Electricity Generation* (Washington, DC: DOE, 2007).
38. U.S. Department of Energy (DOE), *Assessment of Potential Impact of Concentrating Solar Power for Electricity Generation* (Washington, DC: DOE, 2007).
39. Nevada Solar One website. Online at http://www.nevadasolarone.net/the-plant.
40. Cedric Philibert, *The Present and Future Use of Solar Thermal Energy as a Primary Source of Energy* (Paris: IEA/OECD, 2005).
41. CLFR cost based on project cost estimate from California Energy Commission, "Preliminary Staff Assessment for the Carrizo Energy Solar Farm" (2008). On-line at: http://www.energy.ca.gov/2008publications/CEC-700-2008-011/CEC-700-2008-011-PSA.PDF. Estimate includes a 10 percent contingency factor.
42. Vinod Khosla, *Scalable Electric Power from Solar Energy*, The Climate Group (2008).
43. Solar Paces website. On-line at http://www.solarpaces.org/Tasks/Task1/PS10.htm.
44. NREL's Solar Advisor Model shows a shallow optimum for plants with 6 hours of TES versus those with more or less. An EPRI study showed additional storage decreasing LCOE up to 9 hours of storage, but the difference is moderate. Electric Power Research Institute, *New Mexico Central Station Solar Power: Summary Report*, (2008). On-line at http://mydocs.epri.com/docs/public/000000000001016342.pdf.
45. Etan Gumerman and Chris Marnay, *Learning and Cost Reductions for Generating Technologies in the National Energy Modeling System (NEMS)* (Lawrence Berkeley National Laboratory, 2004). On-line at http://repositories.cdlib.org/lbnl/LBNL-52559.
46. Tooraj Jamasb and Jonathan Kohler, *Learning Curves for Energy Technology: A Critical Assessment* (Cambridge, UK: Cambridge University Press, 2007). On-line at http://www.electricitypolicy.org.uk/pubs/wp/eprg0723.pdf.
47. H. Price et al., *DOE Advanced Thermal Energy Storage Development Plan for Parabolic Trough Technology* - DRAFT (U.S. Department of Energy, 2007).
48. See William Nordhaus and Ludo van der Heyden, *Modeling Technological Change: Use of Mathematical Programming Models in the Energy Sector* (1977) and Lena Neij et al., *Experience Curves: A Tool for Energy Policy Assessment* (2003).
49. Global Environment Facility, *Operational Program Number 7* (1995). On-line at http://www.gefweb.org/Operational_Policies/Operational_Programs/OP_7_English.pdf.
50. Dennis Anderson and Kulsum Ahmed, *The Case for Solar Energy Investments*, World Bank Technical Paper No. 279 (1995).
51. International Energy Agency (IEA), *Energy Technology Perspectives 2008* (Paris, IEA/OECD, 2008).
52. Nathan Blair et al., *Concentrating Solar Deployment System (CSDS)—A New Model for Estimating U.S. Concentrating Solar Power (CSP) Market Potential (Preprint)* (Golden, CO: National Renewable Energy Laboratory, 2006).
53. H. Price et al., *DOE Advanced Thermal Energy Storage Development Plan for Parabolic Trough Technology* - DRAFT (U.S. Department of Energy, 2007).
54. They apply different learning rates to the solar field (10 percent) vs. the balance of plant (5 percent), to represent that the solar field is the more complicated component, with newer technology. It was assumed that after three doublings of capacity, the technology cost approaches mature (roughly 4,000-8,000 MW installed).
55. Nathan Blair et al., *Concentrating Solar Deployment System (CSDS)—A New Model for Estimating U.S. Concentrating Solar Power (CSP) Market Potential (Preprint)* (Golden, CO: National Renewable Energy Laboratory, 2006), p. 5.
56. Trough plant, 6 hours of storage per base case methodology (see Appendix A).
57. DLR, *European Concentrated Solar Thermal Roadmapping* (2004), p. 16. On-line at www.promes.cnrs.fr/ACTIONS/Europeenes/downloads/ECOSTAR.Summary.pdf; NREL, *Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts*, Study by Sargent and Lundy (Golden, CO: 2003).
58. "SkyFuel Unveils the SkyTrough: The World's Highest Performance, Lowest Cost Utility-Scale Solar Power System," *GreenTech Media* (October 10, 2008), On-line at http://www.greentechmedia.com/press-releases/skyfuel-unveils-the-skytrough-the-worlds-highest-performance-lowest-cost-utility-scale-solar-power-system-1562.html on October 14, 2008.
59. U.S. Department of Energy (DOE), *Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water* (Washington, DC: DOE, 2006); and L. Stoddard, J. Abiecunas and R. O'Connell, *Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California*, National Renewable Energy Laboratory, NREL/SR-550-39291 (Golden, CO: NREL, 2006).
60. International Energy Agency (IEA), *Energy Technology Perspectives 2008* (Paris, IEA/OECD, 2008).
61. International Energy Agency (IEA), *Energy Technology Perspectives 2008* (Paris, IEA/OECD, 2008).
62. Western Governors' Association (WGA), *Solar Task Force Report* (2006).
63. U.S. Department of Energy (DOE), *Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water* (Washington, DC: DOE, 2006); and L. Stoddard, J. Abiecunas, and R. O'Connell, *Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California*, National Renewable Energy Laboratory, NREL/SR-550-39291 (Golden, CO: NREL, 2006).
64. Robert Monroe, "Lake Mead Could Be Dry by 2021," University of California, San Diego, Press Release, February 12, 2008. On-line at http://ucsdnews.ucsd.edu/newsrel/science/02-08LakeMead.asp.
65. World Wildlife Fund, *An Overview of Glaciers, Glacier Retreat, and Its Subsequent Impacts in the Nepal, India and China* (WWF Nepal Program, 2005). On-line at http://assets.wwfindia.org/downloads/an_overview_of_glaciers_glacier_retreat.pdf.
66. International Energy Agency (IEA), *Energy Technology Perspectives 2008* (Paris, IEA/OECD, 2008).
67. International Energy Agency (IEA), *Energy Technology Perspectives 2008* (Paris, IEA/OECD, 2008).
68. World Resources Institute based on EIA, *Annual Energy Outlook 2008*. Assumes plants have 40 percent capacity factor.
69. U.S. Energy Information Administration (EIA), *Annual Energy Outlook 2008*, DOE/EIA-0383 (2008).
70. 194 MW includes an additional 10% factored in to account for transmission losses.
71. World Resources Institute based on EIA, *Annual Energy Outlook 2008*.
72. NERC data cited in U.S. Department of Energy (DOE), *National Grid Transmission Study*, (2002).
73. Siemens AG, *High Voltage Direct Current Transmission: Proven Technology for Power Exchange*, On-line at http://www.energy.siemens.com/cms/us/US_Products/Portfolio/HVSystemsupto800kV/HighVoltageDCTransmissionSystems/Documents/HVDC_Proven_Technology.pdf. and IEA. 2008. International Energy Agency, *Energy Technology Perspectives 2008*, (IEA/OECD: Paris, 2008).
74. German Aerospace Center (DLR), *Trans-Mediterranean Interconnection for Concentrating Solar Power*, Commissioned by Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2006).

75. A January 2008 *Scientific American* article proposed a "Solar Grand Plan" in which they would use photovoltaic (PV) and CST technologies to generate 69 percent of U.S. electricity needs by 2050. In May 2008, Robert F. Kennedy Jr. outlined "The Next President's First Task," which included the need for investment in the national grid including new DC lines for efficient long-distance transmission. In July 2008, Al Gore highlighted the need for a unified national grid in his "generational challenge" to power America with clean energy within 10 years.
76. German Aerospace Center (DLR), *Solar Electricity Transfer from MENA to Europe* (2006), On-line at http://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/projects/WP01_Technologies_TRANS_Final.pdf.
77. American Electric Power, *Interstate Transmission Vision for Wind Integration*, On-line at http://www.aep.com/about/i765project/docs/WindTransmissionVisionWhitePaper.pdf.
78. The Pickens Plan. On-line at http://www.pickensplan.com.
79. Edison Electric Institute, *EEI Survey of Investment: Historical and Planned Capital Expenditures (1999-2008)* (2005).
80. Joe McGarvey, "Transmission Investment: A Primer," *Electricity Journal,* Vol. 19, No. 8, National Regulatory Research Institute, (Elsevier, 2006), p. 71.
81. Testimony of The Honorable Joseph T. Kelliher, Chairman, Federal Energy Regulatory Commission, before the Committee on Energy and Natural Resources, United States Senate. On-line at http://www.ferc.gov/EventCalendar/Files/20080731102123-Chairmantestimony.pdf.
82. Tata Energy Research Institute and Centre for Renewable Energy Resources, *Status of Solar Thermal Technologies and Markets in India and Europe*, (New Delhi: Organisations for the Promotion of (clean and efficient) Energy Technologies, 2002.)
83. DESERTEC—India website, On-line at http://www.desertec-india.org.in/index.htm.
84. World Bank, *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power* (Washington, DC: World Bank, 2006).
85. World Bank, World Development Indicators 2008.
86. CIA World Factbook. On-line at https://www.cia.gov/library/publications/the-world-factbook/index.html.
87. U.S. Energy Information Administration (EIA), *International Energy Outlook 2008*, DOE/EIA-0484 (2008).
88. U.S. Energy Information Administration (EIA), *International Energy Outlook 2008*, DOE/EIA-0484 (2008).
89. World Resources Institute based on EIA, *International Energy Outlook 2008*.
90. World Resources Institute based on EIA, *International Energy Outlook 2008*.
91. World Bank, "World Bank Supports India's Power Systems with US$600 Million." Press Release, March 18, 2008. On-line at http://web.worldbank.org.
92. World Bank, *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power* (Washington, DC: World Bank, 2006), p. 2.
93. World Bank Global Environment Facility (GEF), *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power*, GEF/C.25/Inf.11 (Washington, DC: World Bank, 2005).
94. World Bank Global Environment Facility (GEF), *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power*, GEF/C.25/Inf.11 (Washington, DC: World Bank, 2005), p. 37.
95. World Bank Global Environment Facility (GEF), *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power*, GEF/C.25/Inf.11 (Washington, DC: World Bank, 2005).
96. World Bank, *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power* (Washington, DC: World Bank, 2006), p. 37; and World Bank Global Environment Facility (GEF), *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power*, GEF/C.25/Inf.11 (Washington, DC: World Bank, 2005), p.210.
97. World Bank, *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power* (Washington, DC: World Bank, 2006).
98. World Bank, *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power* (Washington, DC: World Bank, 2006), p. 37.
99. World Bank, *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power* (Washington, DC: World Bank, 2006), p. 68.
100. World Bank, *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power* (Washington, DC: World Bank, 2006), p. 37.
101. World Bank Global Environment Facility (GEF), *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power*, GEF/C.25/Inf.11 (Washington, DC: World Bank, 2005), p. 40.
102. World Bank Global Environment Facility (GEF), *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power*, GEF/C.25/Inf.11 (Washington, DC: World Bank, 2005), p. 59.
103. World Bank Global Environment Facility (GEF), *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power*, GEF/C.25/Inf.11 (Washington, DC: World Bank, 2005), p. 210.
104. Data supplement to Jonathan G. Dorn, "Solar Thermal Power Comes to a Boil," Earth Policy Institute, July 22, 2008. On-line at http://www.earth-policy.org/Updates/2008/Update73.htm.
105. World Bank, *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power* (Washington, DC: World Bank, 2006), p. 40.
106. African Development Bank, The Ain Beni Mathar Solar Thermal Power Station Project Supplementary Loan, August 2007, On-line at http://www.afdb.org/pls/portal/docs/PAGE/ADB_ADMIN_PG/DOCUMENTS/OPERATIONSINFORMATION/MOROCCO-AIN%20BENI%20MATHAR%20(SUPPLEMENTARY%20LOAN).PDF.
107. World Bank, *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power* (Washington, DC: World Bank, 2006), p. 37; and World Bank Global Environment Facility (GEF), *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power*, GEF/C.25/Inf.11 (Washington, DC: World Bank, 2005), p.210.
108. Christoph Richter, SolarPACES Executive Secretary, Personal Communication, October 17, 2008.
109. Solar Millennium AG, "Solar Millennium AG Signs Framework Agreement with China," Press Release, May 22, 2006. On-line at http://www.solarmillennium.de.
110. World Bank, World Development Indicators 2008.
111. U.S. Energy Information Administration (EIA), *International Energy Outlook 2008*, DOE/EIA-0484 (2008).
112. World Resources Institute based on EIA, *International Energy Outlook 2008*.
113. World Resources Institute based on EIA, *International Energy Outlook 2008*.

114. Trans-Mediterranean Renewable Energy Cooperation (TREC), *Clean Power from Deserts*, White Book (2007), On-line at http://www.nerc.gov.jo/events/TREC/trec_white_paper.pdf.
115. U.S. Energy Information Administration (EIA), *International Energy Outlook 2008*, DOE/EIA-0484 (2008).
116. World Resources Institute based on EIA, *International Energy Outlook 2008*.
117. U.S. Energy Information Administration (EIA), *International Energy Outlook 2008*, DOE/EIA-0484 (2008).
118. The 280 GW of CST capacity quoted incorporates an assumed 10 percent loss in transmitting the power from MENA to Europe.
119. World Resources Institute based on EIA, *International Energy Outlook 2008*.
120. Ralf Christmann, Mediterranean Solar Plan: An Initiative for Sustainable Energy for Europe and the Mediterranean Region, Presentation from the German-French Solar Energy Symposium, Berlin, Germany, December 8, 2008. On-line at http://www.dena.de/fileadmin/user_upload/Download/Veranstaltungen/2008/12/REG/Christmann_on_Mediterranian_Solar_Plan.pdf.
121. European Commission, *Green Paper—Towards A European Strategy for the Security of Energy Supply* (COM(2000) 769, November 2000). On-line at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52000DC0769:EN:HTML.
122. Bar-Lev, Joshua, A Long Term Southwestern Desert Solar Development Policy, BrightSource Energy, Briefing to Environment and Energy Study Institute, September 6, 2007, On-line at http://files.eesi.org/Joshua_Bar-Lev.pdf.
123. Spanish Ministry of Industry, Tourism and Commerce, Orden por la que se revisan las tarifas electricas a partir de 1 de enero 2009. December 10, 2008.
124. e-Parliament website, "Success Story: Feed-In Tariff Supports Concentrating Solar Power in Spain," On-line at http://www.e-parl.net/eparlimages/general/pdf/CSP-Spain%20toolkit.pdf.
125. Electric Power Research Institute, New Mexico Central Station Solar Power: Summary Report, (2008), pp. 5-12.
126. Database of State Incentives for Renewables & Efficiency (DSIRE). On-line at http://www.dsireusa.org/library/includes/incentive2.cfm?Incentive_Code=US06F&State=federal&currentpageid=1&ee=0&re=1.
127. Electric Power Research Institute, *New Mexico Central Station Solar Power: Summary Report*, (2008), pp. 5-12.
128. Electric Power Research Institute, *New Mexico Central Station Solar Power: Summary Report*, (2008), pp. 5-12.
129. World Bank Global Environment Facility (GEF), *Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power,* GEF/C.25/Inf.11 (Washington, DC: World Bank, 2005).
130. David Clement et al., *International Tax Incentives for Renewable Energy: Lessons for Public Policy,* Center for Resource Solutions, Draft Report prepared for Energy Foundation China Sustainable Energy Program (San Francisco: 2005).
131. Export-Import Bank of the United States, "PowerLight Corporation to Export Solar Power Project to Korea with Help from 15-Year Ex-Im Bank Financing," Press Release, July 11, 2006. On-line at http://www.exim.gov/pressreleases.cfm.
132. Export-Import Bank of the United States, "PowerLight Corporation to Export Solar Power Project to Korea with Help from 15-Year Ex-Im Bank Financing," Press Release, July 11, 2006. On-line at http://www.exim.gov/pressreleases.cfm.
133. Jorgen Fenhann, *CDM Pipeline*. Online at http://cd4cdm.org/.
134. Gilbert E. Cohen, *Solar Steam at Nevada Solar One*, Acciona Solar Power, Presented at 14th Biennial CSP SolarPaces Symposium, Las Vegas, NV, March 1-7, 2008. On-line at http://solarpaces2008.sandia.gov/solarpaces%20plenaries/2%20wednesday%20industry%20day%20sessions/1%20plen%20csp%20plants%20today/01%20acciona%20cohen%20solarpaces%202008.pdf.
135. International Energy Agency (IEA), *World Energy Outlook 2006* (Paris: IEA/OECD, 2006), p. 281.
136. U.S. Department of Energy, Energy Efficiency and Renewable Energy, *Solar Energy Technologies Program Multi-Year Program Plan 2007-2011* (2007).
137. U.S. Department of Energy, Energy Efficiency and Renewable Energy, *Solar Energy Technologies Program Multi-Year Program Plan 2007-2011* (2007).
138. U.S. Department of Energy, Energy Efficiency and Renewable Energy, *DOE Solar Energy Technologies Program Annual Report 2007*, DOE/GO-102008-2601 (Golden, CO: NREL, 2008), p. 181.
139. U.S. Department of Energy, Energy Efficiency and Renewable Energy, *Solar Energy Technologies Program Multi-Year Program Plan 2008-2012* (2008), p. 43.
140. European Commission, "Concentrating Solar Power - From Research to Implementation," Luxembourg: Office for Official Publication of the European Communities (2007).
141. European Commission, "Concentrating Solar Power - From Research to Implementation," Luxembourg: Office for Official Publication of the European Communities (2007).
142. European Commission, "Concentrating Solar Power - From Research to Implementation," Luxembourg: Office for Official Publication of the European Communities (2007).
143. Cedric Philibert, "The Present and Future Use of Solar Thermal Energy as a Primary Source of Energy," International Energy Agency (Paris: IEA/OECD, 2005).
144. Cedric Philibert, "The Present and Future Use of Solar Thermal Energy as a Primary Source of Energy," International Energy Agency (Paris: IEA/OECD, 2005).
145. Cedric Philibert, "The Present and Future Use of Solar Thermal Energy as a Primary Source of Energy," International Energy Agency (Paris: IEA/OECD, 2005).
146. Barbara Lockwood, Arizona Public Service, Personal Communication, August 14, 2008.
147. Analysis by NREL does not show state RPSs having a strong impact on deployment through 2030, which may be because the technology becomes the least-cost best-fit option in the future with or without the RPS. However, in the short term it has had a qualitative impact as described. See Nathan Blair et al., *Modeling the Impact of State and Federal Incentives on Concentrating Solar Power Market Penetration*, National Renewable Energy Laboratory, NREL/CD-550-42709. Barbara Lockwood, Arizona Public Service, Personal Communication, August 14, 2008.
148. California Public Utilities Commission website. On-line at http://docs.cpuc.ca.gov/energy/electric/renewableenergy/qandas/marketpricereferent.htm.
149. Tim Duane, Personal Communication, November 11, 2008.
150. Black & Veatch, *Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California* (Golden, CO: National Renewable Energy Laboratory, 2006), p. 45.
151. SCHOTT AG, "SCHOTT Memorandum on Solar Thermal Plant Technology," (2005). On-line at http://www.schott.com/solar/english/download/schott_memorandum_e.pdf.
152. In this case, where there is a second renewal, the plants already in development also benefit.
153. Solar Energy Industries Association (SEIA), *Provisions in H.R. 1424 Emergency Economic Stabilization Act of 2008 Benefiting the U.S. Solar Energy Market and Businesses, Utilities and Homeowners That Install Solar Energy Systems* (2008). On-line at http://www.seia.org/galleries/pdf/HR_1424_Solar_Memo.pdf.
154. Comments by Mathew Meares, HSH Nordbank from Project Finance panel of CPV and CSP Investment and Finance Summit USA 2008, San Francisco, CA, October 2-3, 2008.

155. California Electricity Commission, *2007 Integrated Energy Policy Report*, CEC-100-2007-008-CMF (2007).
156. e-Parliament website, "Success Story: Feed-In Tariff Supports Concentrating Solar Power in Spain," On-line at http://www.e-parl.net/eparlimages/general/pdf/CSP-Spain%20toolkit.pdf.
157. SolarPACES website. Online at http://www.solarpaces.org/News/news.htm.
158. Jane Burgermeister, "Low-cost Solar Thermal Plants at Heart of Algerian-German Research Push," *RenewableEnergyWorld* (Vienna, Austria: March 20, 2008). On-line at http://www.renewableenergyworld.com/rea/news/story?id=51889.
159. Jane Burgermeister, "Low-cost Solar Thermal Plants at Heart of Algerian-German Research Push," *RenewableEnergyWorld* (Vienna, Austria: March 20, 2008). On-line at http://www.renewableenergyworld.com/rea/news/story?id=51889.
160. Government of India, Prime Minister's Council on Climate Change, *National Action Plan on Climate Change* (2008). On-line at http://pmindia.nic.in/Pg01-52.pdf.
161. The ITC is value is 30 percent of the initial investment made, as it would be paid in Year 1 when the plant enters into service. The value of the FIT is the above-market premium paid per kWh. The Spanish FIT law, as stated in the "Orden por la que se revisan las tarifas electricas a partir de 1 de enero de 2009," gives developers two options for the feed-in tariff payment, the second of which is to sell their power on the spot market and earn a "Prima", or above-market premium for their power. Projects can also opt to receive a fixed price of 28.7 euro cents. This calculation uses the 27 euro-cent above-market premium (which declines to 21 cents after 25 years) as the subsidy rate, multiplied by the generation of MWh to calculate subsidy value. For each year, it is shown in real dollars, meaning it is corrected for inflation. The value to the developer is calculated using the relevant discount rate. See "Orden por la que se revisan las tarifas electricas a partir de 1 de enero de 2009. " Published by the Ministry of Industry, Tourism, and Commerce.
162. Spanish Government, Real Decreto 661/2007. On-line at http://noticias.juridicas.com/base_datos/Anterior/r2-rd661-2007.html#c4s2**.**
163. Jose Martin, *Solar Tres,* National Renewable Energy Laboratory CSP Technology Workshop, Denver, CO, March 7, 2007. On-line at http://www.nrel.gov/csp/troughnet/pdfs/2007/martin_solar_tres.pdf.
164. U.S. Environmental Protection Agency (EPA), *EPA Analysis of the Lieberman-Warner Climate Security Act of 2008* (2008). On-line at http://www.epa.gov/climatechange/downloads/s2191_EPA_Analysis.pdf.
165. Paltsev et al., *Assessment of U.S. Cap-and-Trade Proposals*, MIT Joint Program on the Science and Policy of Global Change (Report 146, Appendix D, 2007). On-line at http://mit.edu/globalchange/www/abstracts.html#a146.
166. Primary Certified Emission Reduction (CER) price range, as described in PointCarbon, *CDM & JI Monitor* (Vol. 6, Issue 19, October 1, 2008). Primary price is quoted as opposed to secondary trading price, because that is the price typically paid to the first supplier of CERs.
167. Alan Miller, "The Global Environment Facility Program to Commercialize New Energy Technologies," In *Energy for Sustainable Development*, Journal of the International Energy Initiative, Volume XI, No 1 (2007). GEF, *Climate Change Program Study*, Led by Anton Eberhard, Office of Monitoring and Evaluation (2004).
168. Global Environment Facility, Scientific and Technical Advisory Panel, "Reducing Long Term Costs of Low Greenhouse Gas-Emitting Technologies," United Nations Environment Programme (2004).
169. Alan Miller, "The Global Environment Facility Program to Commercialize New Energy Technologies," In *Energy for Sustainable Development*, Journal of the International Energy Initiative, Volume XI, No 1 (2007).
170. GEF, *Climate Change Program Study*, Led by Anton Eberhard, Office of Monitoring and Evaluation (2004). Alan Miller, "The Global Environment Facility Program to Commercialize New Energy Technologies," In *Energy for Sustainable Development*, Journal of the International Energy Initiative, Volume XI, No 1 (2007).
171. Alan Miller, "The Global Environment Facility Program to Commercialize New Energy Technologies," In *Energy for Sustainable Development*, Journal of the International Energy Initiative, Volume XI, No 1 (2007).
172. Taryn Fransen, Hilary McMahon, and Smita Nakhooda, "Measuring the Way to a New Global Climate Agreement," World Resources Institute Discussion Paper, (2008). On-line at http://pdf.wri.org/measuring_the_way_to_a_new_global_climate_agreement.pdf.
173. Morgan Bazillian et al., *Considering technology within the UN climate change negotiations*. Energy Research Center of the Netherlands (2008). On-line at http://regserver.unfccc.int/seors/attachments/file_storage/wlc0zq26lnyrt0g.pdf.
174. Britt Childs Staley, Jenna Goodward, and Hilary McMahon, "From Positions to Agreement: Technology and Finance at the UNFCCC," World Resources Institute Discussion Paper (2008). On-line at http://pdf.wri.org/from_positions_to_agreement.pdf.
175. A 6 percent contingency is used as indicative. See, for example, Bruce Kelly, *Nexant Parabolic Trough Solar Power Plant Systems Analysis,* National Renewable Energy Laboratory (Golden, CO: NREL, 2006). p. 23.
176. Solar Advisor Model (SAM), U.S. Department of Energy, National Renewable Energy Laboratory website. On-line at https://www.nrel.gov/analysis/sam/cost_data.html.
177. David Wheeler and Kevin Ummel, *Desert Power: The Economics of Solar Thermal Electricity for Europe, North Africa, and the Middle East*, Center for Global Development, Working Paper Number 156 (Washington D.C.: 2008).

Bibliography

African Development Bank. 2007. *The Ain Beni Mathar Solar Thermal Power Station Project Supplementary Loan*. Online at http://www.afdb.org/pls/portal/docs/page/adb_admin_pg/documents/operationsinformation/morocco-ain%20beni%20mathar%20(supplementary%20loan).pdf

American Electric Power. *Interstate Transmission Vision for Wind Integration*. Accessed on October 21, 2008. Online at http://www.aep.com/about/i765project/docs/WindTransmissionVisionWhitePaper.pdf.

Anderson, Dennis and Kulsum Ahmed. 1995. *The Case for Solar Energy Investments.* World Bank Technical Paper No. 279.

Bar-Lev, Joshua. 2007. *A Long Term Southwestern Desert Solar Development Policy.* BrightSource Energy. Briefing to Environment and Energy Study Institute, September 6, 2007. Accessed on October 28, 2008. Online at http://files.eesi.org/Joshua_Bar-Lev.pdf.

Bazillian, Morgan, et al. 2008. *Considering Technology within the UN Climate Change Negotiations*. Energy Research Center of the Netherlands. Available online at: http://regserver.unfccc.int/seors/attachments/file_storage/wlc0zq26lnyrt0g.pdf.

Black & Veatch. 2006. *Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California*. Golden, CO: National Renewable Energy Laboratory.

Blair, Nathan. 2008. *The Solar Advisor Model and its Usage for the Solar America Initiative*. National Renewable Energy Laboratory Seminar Series Archive. Accessed on October 24, 2008. Online at http://www.nrel.gov/analysis/seminar/archive.html.

Blair, Nathan. 2006. *Concentrating Solar Deployment System (CSDS)—A New Model for Estimating U.S. Concentrating Solar Power (CSP) Market Potential (Preprint)*. Golden, CO: National Renewable Energy Laboratory.

BrightSource Energy website. 2007. Accessed October 8, 2008. Online at http://www.brightsourceenergy.com/faq.htm.

Burgermeister, Jane. 2008. "Low-cost Solar Thermal Plants at Heart of Algerian-German Research Push."*RenewableEnergyWorld*. Vienna, Austria. March 20, 2008. Online at http://www.renewableenergyworld.com/rea/news/story?id=51889.

California Electricity Commission. *2007 Integrated Energy Policy Report*. CEC-100-2007-008-CMF.

California Public Utilities Commission. 2004. *Revised 2004 Market Price Referent (MPR) Staff Report*. Online at http://docs.cpuc.ca.gov/published/Rulings/43825.htm.

California Public Utilities Commission website. Accessed on October 10, 2008. Online at http://docs.cpuc.ca.gov/energy/electric/renewableenergy/qandas/marketpricereferent.htm.

Christmann, Ralf. 2008. *Mediterranean Solar Plan: An Initiative for Sustainable Energy for Europe and the Mediterranean Region*. Presentation from the German-French Solar Energy Symposium, Berlin, Germany, December 8, 2008. Accessed on January 16, 2009. Online at http://www.dena.de/fileadmin/user_upload/Download/Veranstaltungen/2008/12/REG/Christmann_on_Mediterranian_Solar_Plan.pdf

CIA World Factbook. Accessed September 25, 2008. Online at https://www.cia.gov/library/publications/the-world-factbook/index.html.

Clement, David et al. 2005. *International Tax Incentives for Renewable Energy: Lessons for Public Policy*. Center for Resource Solutions. Draft Report prepared for Energy Foundation China Sustainable Energy Program.

Cohen, Gilbert E. *Solar Steam at Nevada Solar One*. Acciona Solar Power. Presentation at 14th Biennial CSP SolarPaces Symposium, Las Vegas, NV, March 1-7, 2008. Accessed on October 28, 2008. Online at http://solarpaces2008.sandia.gov/solarpaces%20plenaries/2%20wednesday%20industry%20day%20sessions/1%20PLEN%20CSP%20PLANTS%20TODAY/01%20acciona%20cohen%20solarpaces%202008.pdf.

Database of State Incentives for Renewables and Efficiency (DSIRE). Accessed on October 29, 2008. Online at http://www.dsireusa.org/.

DESERTEC—India website. Accessed on September 25, 2008. Online at http://www.desertec-india.org.in/index.htm.

DESERTEC-UK website. Accessed January 9, 2009. Online at http://www.trec-uk.org.uk/index.htm.

Dorn, Jonathan G. 2008. "Solar Thermal Power Comes to a Boil." Earth Policy Institute. Accessed on October 10, 2008. Online at http://www.earth-policy.org/Updates/2008/Update73.htm.

Edison Electric Institute. 2005. *EEI Survey of Investment: Historical and Planned Capital Expenditures (1999-2008).*

Electric Power Research Institute. 2008. *New Mexico Central Station Solar Power: Summary Report*. EPRI, Palo Alto, CA; PNM Resources, Inc., Albuquerque, NM; El Paso Electric Co., El Paso, TX; San Diego Gas & Electric Co., San Diego, CA; Southern California Edison Co., Rosemead, CA; Tri-State Generation & Transmission Association, Inc., Westminster, CO; and Xcel Energy Services, Inc., Denver, CO: 2008. 1016342.

Energy Information Administration (EIA). 2008. *Annual Energy Outlook 2008.* Washington, DC: DOE/EIA. DOE/EIA-0383.

Energy Information Administration (EIA). 2008. *International Energy Outlook 2008*. Washington, DC: DOE/EIA. DOE/EIA-0484.

Energy Information Administration (EIA). 2007. *Assumptions to the Annual Energy Outlook 2007*. Washington, DC: DOE/EIA. Online at http://www.eia.doe.gov/oiaf/archive/aeo07/assumption/index.html.

e-Parliament website. "Success Story: Feed-In Tariff Supports Concentrating Solar Power in Spain," Accessed on October 29, 2008. Online at http://www.e-parl.net/eparlimages/general/pdf/CSP-Spain%20toolkit.pdf.

European Commission. 2007. *Concentrating Solar Power - From Research to Implementation*. Luxembourg: Office for Official Publications of the European Communities.

European Commission. 2000. *Green Paper—Towards A European Strategy for the Security of Energy Supply*. COM(2000) 769, November 2000. Accessed on January 16, 2009. Available online at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52000DC0769:EN:HTML

European Commission website. Accessed on October 29, 2008. Online at http://ec.europa.eu/research/energy/nn/nn_rt/nn_rt_cs/article_1117_en.htm.

Export-Import Bank of the United States. 2006. "PowerLight Corporation to Export Solar Power Project to Korea with Help from 15-Year Ex-Im Bank Financing." Press Release, July 11, 2006. Accessed on October 10, 2008. Online at http://www.exim.gov/pressreleases.cfm.

Federal Energy Regulatory Commission. 2008. "Testimony of the Honorable Joseph T. Kelliher, Chairman, Federal Energy Regulatory Commission before the Committee on Energy and Natural Resources, United States Senate." Accessed on October 10, 2008. Online at http://www.ferc.gov/EventCalendar/Files/20080731102123-Chairmantestimony.pdf.

Fenhann, Jorgen. *CDM Pipeline.* Online at http://cd4cdm.org/.

Fransen, Taryn, Hilary McMahon, and Smita Nakhooda. 2008. "Measuring the Way to a New Global Climate Agreement," World Resources Institute Discussion Paper. Online at: http://pdf.wri.org/measuring_the_way_to_a_new_global_climate_agreement.pdf.

German Aerospace Center (DLR). 2006. *Solar Electricity Transfer from MENA to Europe*. Accessed on November 19, 2008. Online at http://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/projects/WP01_Technologies_TRANS_Final.pdf.

German Aerospace Center (DLR). 2006. *Trans-Mediterranean Interconnection for Concentrating Solar Power*. Commissioned by Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

German Aerospace Center (DLR). 2004. *European Concentrated Solar Thermal Roadmapping*. Online at www.promes.cnrs.fr/ACTIONS/Europeenes/downloads/ECOSTAR.Summary.pdf.

Global Environment Facility. 2004. *Climate Change Program Study*. Led by Anton Eberhard. Office of Monitoring and Evaluation.

Global Environment Facility. 1995. *Operational Program Number 7*. Accessed on January 28, 2009. Online at http://www.gefweb.org/Operational_Policies/Operational_Programs/OP_7_English.pdf.

Global Environment Facility, Scientific and Technical Advisory Panel. 2004. "Reducing Long Term Costs of Low Greenhouse Gas-Emitting Technologies." United Nations Environment Programme.

Government of India. Prime Minister's Council on Climate Change. 2008. *National Action Plan on Climate Change*. Online at http://pmindia.nic.in/Pg01-52.pdf.

Greentech Media website. 2008. "SkyFuel Unveils the SkyTrough: The World's Highest Performance, Lowest Cost Utility-Scale Solar Power System." Accessed on October 14, 2008. Online at http://www.greentechmedia.com/press-releases/skyfuel-unveils-the-sky-trough-the-worlds-highest-performance-lowest-cost-utility-scale-solar-power-system-1562.html.

Gumerman, Etan and Chris Marnay. 2004. *Learning and Cost Reductions for Generating Technologies in the National Energy Modeling System (NEMS)*. Lawrence Berkeley National Laboratory. Accessed on October 28, 2008. Online at http://repositories.cdlib.org/lbnl/LBNL-52559.

Harvard Energy Journal Club. 2007. "Overview of Solar Thermal Technologies." Accessed on October 24, 2008. Online at http://www.hcs.harvard.edu/~hejc/papers/Solar%20Jan07/solar_thermal_overview.pdf.

International Atomic Energy Agency (IAEA). 1997. *Sustainable Development & Nuclear Power*. Vienna: IAEA.

International Energy Agency (IEA). 2008. *Energy Technology Perspectives 2008*. Paris: IEA/OECD.

International Energy Agency (IEA). 2007. *World Energy Outlook 2007*. Paris: IEA/OECD.

International Energy Agency (IEA). 2006. *World Energy Outlook 2006*. Paris: IEA/OECD.

Jamasb, Tooraj and Jonathan Kohler. 2007. *Learning Curves for Energy Technology: A Critical Assessment*. Cambridge, UK: Cambridge University Press. Accessed on October 28, 2008. Online at http://www.electricitypolicy.org.uk/pubs/wp/eprg0723.pdf.

Khosla, Vinod. 2008. *Scalable Electric Power from Solar Energy*. The Climate Group.

Kutscher, Chuck. 2008. *Cooling Options for Geothermal and Concentrated Solar Thermal Power Plants*. National Renewable Energy Laboratory. Presentation from the EPRI Workshop on Advanced Cooling Technologies, July 9, 2008. Online at http://mydocs.epri.com/docs/AdvancedCooling/PresentationsDay2/13_EPRI%20Presentation-3%20(NX-PowerLite)_Kutscher.pdf.

Leitner, Arnold. 2002. *Fuel from the Sky: Solar Power's Potential for Western Energy Supply*. National Renewable Energy Laboratory. NREL/SR-550-32160.

Martin, Jose. 2007. *Solar Tres,* National Renewable Energy Laboratory CSP Technology Workshop, Denver, CO, March 7, 2007. Accessed on October 28, 2008. Online at http://www.nrel.gov/csp/troughnet/pdfs/2007/martin_solar_tres.pdf.

Martin, Jose. 2007. *Andasol 1&2*. National Renewable Energy Laboratory Trough Technology Workshop, Denver, CO, March 8, 2007. Accessed on November 3, 2008. Online at http://www.nrel.gov/csp/troughnet/pdfs/2007/martin_andasol_pictures_storage.pdf.

Miller, Alan. 2007. "The Global Environment Facility Program to Commercialize New Energy Technologies." In *Energy for Sustainable Development*, Journal of the International Energy Initiative. Volume XI. No 1. March 2007.

Mills, David and Robert Morgan. 2008. Solar Thermal Electricity as a Primary Replacement for Coal and Oil in U.S. Generation and Transport. SolarPACES Symposium, Las Vegas, NV, March 5, 2008. Online at http://solarpaces2008.sandia.gov/solarpaces%20plenaries/2%20wednesday%20industry%20day%20sessions/3%20market%20outlook/03%20ausra.pdf.

Monroe, Robert. 2008. "Lake Mead Could Be Dry by 2021." University of California, San Diego. Press Release, February 12, 2008. Accessed on November 18, 2008. Online at http://ucsdnews.ucsd.edu/newsrel/science/02-08LakeMead.asp.

Moran, Susan and J. Thomas McKinnon. 2008. "Hot Times for Solar Energy." World Watch. Vol. 21, No. 2, March/April 2008.

Muller-Steinhagen, Hans and Freng and Franz Trieb. 2004. "Concentrating Solar Power for Sustainable Electricity Generation." Ingenia. Issue 19, May 2004.

National Energy Technology Laboratory (NETL). 2007. Cost and Performance Baseline for Fossil Energy Plants. Vol. 1. DOE/NETL-2007/1281.

National Energy Technology Laboratory (NETL). 2002. Major Environmental Aspects of Gasification-Based Power Generation Technologies.

National Renewable Energy Laboratory. Solar Advisor Model (SAM). Online at https://www.nrel.gov/analysis/sam/cost_data.html.

National Renewable Energy Laboratory. 2003. Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts. Golden, CO: NREL.

Nevada Solar One website. Accessed on November 12, 2008. Online at www.nevadasolarone.net.

Ortega, J. Ignacio et al. 2006. Central Receiver System (CRS) Solar Power Plant Using Molten Salt as Heat Transfer Fluid. Online at www.sener.es/eportal_docs/general/file-cwa0fcc36424ab41b7bf04/solartres.pdf.

Pacala, S. and R. Socolow. 2004. "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies." Science. Vol. 305, August 13, 2004.

Pacca, S. and Horvath, A. 2002. "Greenhouse Gas Emissions from Building and Operating Electric Power Plants in the Upper Colorado River Basin." Environmental Science and Technology. 36(14), 3194-3200.

Paltsev et al. 2007. Assessment of U.S. Cap-and-Trade Proposals. MIT Joint Program on the Science and Policy of Global Change. Report 146, Appendix D. Accessed on October 28, 2008. Online at http://mit.edu/globalchange/www/abstracts.html#a146.

Philibert, Cedric. 2005. The Present and Future Use of Solar Thermal Energy as a Primary Source of Energy. International Energy Agency (IEA). Paris: IEA/OECD.

The Pickens Plan website. Accessed on October 21, 2008. Online at http://www.pickensplan.com.

Price, H. 2003. Due Diligence Study of Parabolic Trough and Power Tower Technologies. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Online at http://www.nrel.gov/analysis/seminar/docs/2003/hank_price_presentation.ppt.

Price, H. et al. 2007. DOE Advanced Thermal Energy Storage Development Plan for Parabolic Trough Technology (DRAFT). U.S. Department of Energy.

SCHOTT AG. 2005. "SCHOTT Memorandum on Solar Thermal Plant Technology." Accessed on October 10, 2008. Online at http://www.schott.com/solar/english/download/schott_memorandum_e.pdf.

Seager, Richard et al. 2007. "Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America." Science. Vol. 316, No. 5828, pp. 1181–1184. May 25, 2007.

Siemens AG. High Voltage Direct Current Transmission: Proven Technology for Power Exchange. Accessed on October 28, 2008. Online at http://www.energy.siemens.com/cms/us/US_Products/Portfolio/HVSystemsupto800kV/HighVoltageDCTransmissionSystems/Documents/HVDC_Proven_Technology.pdf.

Solar Advisor Model (SAM), U.S. Department of Energy, National Renewable Energy Laboratory website. Online at https://www.nrel.gov/analysis/sam/cost_data.html.

Solar Energy Industries Association (SEIA). 2008. Provisions in H.R. 1424 Emergency Economic Stabilization Act of 2008 Benefiting the U.S. Solar Energy Market and Businesses, Utilities and Homeowners That Install Solar Energy Systems. Accessed on October 28, 2008. Online at http://www.seia.org/galleries/pdf/HR_1424_Solar_Memo.pdf.

Solar Millennium AG. 2008. "Solar Millennium AG Signs Framework Agreement with China." Press Release, May 22, 2006. Accessed on October 14, 2008. Online at http://www.solarmillennium.de.

SolarPACES. Solar Dish Engines. Accessed on October 24, 2008. Online at http://www.solarpaces.org/CSP_Technology/docs/solar_dish.pdf.

SolarPACES website. Online at http://www.solarpaces.org/Tasks/Task1/PS10.htm.

Spanish Government. Real Decreto 661/2007. Online at http://noticias.juridicas.com/base_datos/Anterior/r2-rd661-2007.html#c4s2.

Spanish Ministry of Industry, Tourism and Commerce. 2008. Orden por la que se revisan las tarifas electricas a partir de 1 de enero 2009. December 10, 2008.

Staley, Britt Childs, Jenna Goodward, and Hilary McMahon. 2008. "From Positions to Agreement: Technology and Finance at the UNFCCC." World Resources Institute Discussion Paper. Available online at http://pdf.wri.org/from_positions_to_agreement.pdf.

Stoddard, L., J. Abiecunas, and R. O'Connell. 2006. Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California. National Renewable Energy Laboratory. NREL/SR-550-39291.

Tata Energy Research Institute and Centre for Renewable Energy Resources. 2002. Status of Solar Thermal Technologies and Markets in India and Europe. New Delhi: Organisations for the Promotion of (clean and efficient) Energy Technologies.

Testimony of the Honorable Joseph T. Kelliher, Chairman, Federal Energy Regulatory Commission before the Committee on Energy and Natural Resources, United States Senate, October 10, 2008. Online at http://www.ferc.gov/EventCalendar/Files/20080731102123-Chairmantestimony.pdf.

Trans-Mediterranean Renewable Energy Cooperation (TREC). 2007. Clean Power from Deserts. White Book. Accessed on October 28, 2008. Online at http://www.nerc.gov.jo/events/TREC/trec_white_paper.pdf.

Trans-Mediterranean Renewable Energy Cooperation (TREC). Clean Power from Deserts. Accessed on October 28, 2008. Online at http://www.trec-uk.org.uk/resources/csp_talk4.ppt; and German Aerospace Center (DLR). 2006. Trans-Mediterranean Interconnection for Concentrating Solar Power. Commissioned by Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

U.S. Department of Energy (DOE). 2007. Assessment of Potential Impact of Concentrating Solar Power for Electricity Generation. Washington, DC: DOE.

U.S. Department of Energy (DOE). 2006. Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water. Washington, DC: DOE.

U.S. Department of Energy (DOE). 2002. National Grid Transmission Study. Washington, DC: DOE.

U.S. Department of Energy, Energy Efficiency and Renewable Energy. 2008. DOE Solar Energy Technologies Program Annual Report 2007. DOE/GO-102008-2601. Golden, CO: NREL.

U.S. Department of Energy, Energy Efficiency and Renewable Energy. 2007. Solar Energy Technologies Program Multi-Year Program Plan 2007-2011.

U.S. Environmental Protection Agency (EPA). 2008. EPA Analysis of the Lieberman-Warner Climate Security Act of 2008. Accessed on October 28, 2008. Online at http://www.epa.gov/climatechange/downloads/s2191_EPA_Analysis.pdf.

U.S. Geological Survey. 2008. Mineral Commodity Summaries 2008. Washington, DC: USGS.

Van Atten, Christopher, Thomas Curry, and Amlan Saha. 2008. Benchmarking Air Emissions of the 100 Larges Electric Power Producers in the United States. Collaborative publication by Ceres, the Natural Resources Defense Council (NRDC), Public Service Enterprise Group (PSEG), and PG&E Corporation.

Western Governors' Association (WGA). 2006. Solar Task Force Report. Commissioned by the Western Governors' Association's Clean and Diversified Energy Advisory Committee (CDEAC).

Wheeler, David and Kevin Ummel. 2008. XXX Washington DC: Center for Global Development.

World Bank. 2008. "World Bank Supports India's Power Systems with US$600 Million." Press Release, March 18, 2008. Accessed on October 10, 2008. Online at http://web.worldbank.org.

World Bank. 2006. Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power. Washington, DC: World Bank.

World Bank Global Environment Facility (GEF). 2005. Assessment of the World Bank/GEF Strategy for the Market Development of Concentrating Solar Thermal Power. GEF/C.25/Inf.11. Washington, DC: World Bank.

World Resources Institute. Climate Analysis Indicators Tool. Online at http://cait.wri.org.

World Wildlife Fund. 2005. An Overview of Glaciers, Glacier Retreat, and Its Subsequent Impacts in the Nepal, India and China. WWF Nepal Program. Accessed on November 18, 2008. Online at http://assets.wwfindia.org/downloads/an_overview_of_glaciers_glacier_retreat.pdf.

World Bank. World Development Indicators 2008.

Zweibel, Ken et al. 2008. "A Solar Grand Plan." Scientific American. January 2008, pp. 64-73.

About WRI

The World Resources Institute (WRI) is an environmental think tank that goes beyond research to find practical ways to protect the earth and improve people's lives.

Our mission is to move human society to live in ways that protect Earth's environment and its capacity to provide for the needs and aspirations of current and future generations.

Because people are inspired by ideas, empowered by knowledge, and moved to change by greater understanding, WRI provides—and helps other institutions provide—objective information and practical proposals for policy and institutional change that will foster environmentally sound, socially equitable development.

WRI organizes its work around four key programmatic goals:

- **People & Ecosystems:** Reverse rapid degradation of ecosystems and assure their capacity to provide humans with needed goods and services.
- **Governance:** Empower people and support institutions to foster environmentally sound and socially equitable decision-making.
- **Climate Protection:** Protect the global climate system from further harm due to emissions of greenhouse gases and help humanity and the natural world adapt to unavoidable climate change.
- **Markets & Enterprise:** Harness markets and enterprise to expand economic opportunity and protect the environment.

About the Authors

Britt Childs Staley is an Associate with WRI's international climate policy team. Her research primarily focuses on clean technology deployment, including regulatory and investment frameworks to facilitate market penetration of new energy technologies.

Jenna Goodward is a former Research Analyst with WRI's international climate policy team. She is currently researching renewable energy policy and markets at the Laboratório Interdisciplinar de Meio Ambiente (LIMA) in Brazil as a Fulbright Fellow.

Clayton Rigdon is a Research Analyst on the Capital Markets Research team at WRI. He conducts research and analysis on a variety of environmental finance topics primarily focusing on financial and competitive implications of climate change.

Andrew MacBride is a former researcher for WRI. He currently works for Cocentric Energy Advisors.

WORLD
RESOURCES
INSTITUTE

10 G Street, NE
Washington, DC 20002
www.wri.org

WORLD RESOURCES INSTITUTE

in conjunction with...

Goldman Sachs

Center for Environmental Markets

ISBN: 978-1-56973-725-5