VALUE PROPOSITION OF LARGE-SCALE SOLAR POWER TECHNOLOGIES IN CALIFORNIA

CENTER FOR ENERGY EFFICIENCY AND RENEWABLE TECHNOLOGIES
SACRAMENTO, CALIFORNIA

Lori Smith Schell, Ph.D

Empowered Energy

May 2009

Table of Contents

VALUE PROPOSITION OF LARGE-SCALE SOLAR POWER TECHNOLOGIES IN CALIFORNIA – DESCRIPTION OF METHODOLOGY

I. INTRODUCTION

Solar energy is the largest renewable energy resource worldwide. The energy in sunlight reaching the earth in just 70 minutes is equivalent to annual global energy consumption, making the potential for solar power virtually unlimited.[1] This analysis examines the benefits that non-utility investment in large-scale (~10 MW and larger) solar power technologies can provide to California today. These benefits range from 13.9-32.7 cents/kilowatt-hour ("cents/kWh") for solar-generated electricity that displaces central station power generated during peak demand periods, to 9.4-22.9 cents/kWh for solar-generated electricity that displaces central station baseload power. It must be emphasized that this report is intended to quantify the benefits provided by large-scale solar power technologies based on the quantification of attributes of these technologies; this report does not consider solar technology costs or power purchase agreement costs. Large-scale solar power technologies also have the potential to make a significant contribution to California's 2020 greenhouse gas reduction goals under the California Global Warming Solutions Act of 2006 ("AB 32").

This analysis is based on the operating characteristics of the six large-scale solar power technologies listed below, each of which is assumed to operate without hybridization with fossil-fueled generators. This analysis examines solar-only operation that occurs only when there is ample sunlight available, and operation with limited thermal energy storage ("TES"), where applicable. An asterisk indicates those large-scale solar power technologies that may be integrated with TES, thereby enabling the dispatch of solar-generated electricity.

Thermal Electric Systems[2]

- Parabolic trough systems *
- Dish/engine systems
- Solar power tower systems *
- Compact linear Fresnel systems *

Photovoltaic Systems

- Concentrating photovoltaic ("PV") systems
- Large-scale (non-concentrating) PV systems.

---

1 Earth Policy Institute, 2008, p. 1.

2 Only thermal electric systems that use oil or molten salt as the heat transfer medium currently have a technically and economically viable method for TES. Dish/engine systems, which use hydrogen or helium gas as the heat transfer medium, have not generally been used with solar energy storage in the form of heat, though development efforts are underway to demonstrate the feasibility of doing so. *See* U.S. Department of Energy, September 19, 2008, p. 2.

In general terms, thermal electric systems concentrate direct sunlight using mirrors or reflectors, and then use the resultant heat to operate an engine or to raise steam to drive turbines and generators, similar to a conventional power plant.[3] In the latter respect, thermal electric systems include technologies familiar to utilities. PV systems, in contrast, generate electricity directly within the solar panel or thin film medium, without the need for turbines or separate generators.[4] This report characterizes both categories of solar power technologies – thermal electric and PV – as a single group called Large-Scale Solar Power ("LSSP"). A brief description of each of these six LSSP technologies is provided in Appendix A.

Depending on size and technology, LSSP electric generating plants may be located anywhere on the electric grid, *i.e.*, on the high voltage transmission system, on the lower voltage distribution system, or even on the site of a large electricity consuming customer. LSSP generating plants located on-site or on the distribution may therefore have some characteristics of distributed generation in terms of avoiding the need for transmission and distribution ("T&D") capacity and its related line losses.

The value proposition of non-utility investment in LSSP plants in California is based on the ability of the LSSP systems to displace electricity generation from fossil-fueled generators, thereby avoiding or deferring the need to build new fossil-fueled generators. LSSP systems without TES are largely a peaking resource, though electricity generation from such solar-only LSSP systems tends to peak several hours earlier than California's mid-afternoon peak demand period. LSSP systems with TES may either have an extended range of operating hours and operate as an intermediate load generation resource or rely on TES to enhance peak period availability. Valuing the avoided costs associated with the deployment of LSSP systems must therefore be based on a comparison with the relevant avoided generation technology serving California customers in both the peak and the intermediate demand period.

- For the natural gas-fired peaking unit, the avoided costs are derived from inputs to the greenhouse gas modeling done by Energy and Environmental Economics, Inc. ("E3") on behalf of the California Public Utilities Commission ("CPUC") to model the electricity sector's compliance with AB 32.[5]

---

[3] Renewable Energy Focus, January/February 2008, p. 43.

[4] PV systems generate direct-current ("DC") electricity, which requires a separate power inverter to convert the DC electricity into alternating-current ("AC") electricity; AC electricity is the dominant type of electricity used in the United States.

[5] Energy and Environmental Economics, Inc., May 13, 2008, "Gen Cost" tab. Because the CPUC no longer specifies an MPR for a natural gas-fired peaking unit, the E3 greenhouse gas modeling results were used because they are relatively recent and were developed for the CPUC.

- For the intermediate central station generating technology, most of the avoided costs are derived from the natural gas combined cycle parameters that define the CPUC's 2008 Market Price Referent ("MPR") proxy plant.[6]

This analysis provides a "bookend" approach that brackets the value proposition of LSSP systems by providing separate calculations for the avoided generation technology in each demand period. In reality, LSSP systems will displace a continually changing mix of natural gas-fired peaking and combined cycle generating units.

Avoiding fossil-fueled electricity generation avoids: (i) Fossil fuel use and delivery-related emissions, (ii) exposure to fossil fuel price volatility, and (iii) combustion-related air emissions. Avoided air emissions result in health benefits for Californians and reductions in greenhouse gas emissions. Depending on location, LSSP systems may add value in avoiding the need for distribution and/or transmission capacity and related line losses. Finally, increased penetration of LSSP systems provides job creation potential through increases in limited-term construction jobs, ongoing operations and maintenance jobs (in lieu of expenditure on fossil fuels), and the potential for increased in-state manufacturing capacity.

In this analysis, the value proposition of LSSP is based on avoided costs and emissions attributed to non-utility investment in LSSP systems, but all values are expressed in terms of cents/kWh of LSSP electricity generated. The cumulative dollar value attributed to the displacement of natural gas-fired generation by LSSP systems can be approximated by multiplying the cents/kWh value times the kWh of LSSP electricity generated. Separate value propositions are calculated for the displacement of electricity generation from a peaking unit and from a combined cycle unit by solar-generated electricity from LSSP systems (with TES, where applicable). The results of these analyses are summarized in the "waterfall" chart in Figure 1 for displacement of a peaking unit and in Figure 2 for displacement of a combined cycle unit; both avoided generating units are assumed to be in-state and natural gas-fired. The derivation of the value of each of the value components included in the waterfall charts is described in detail in the body of the report.

Although the value proposition of LSSP technologies in Figure 1 and Figure 2 include only benefits attributable to these technologies, incremental ***net*** benefits can be calculated by subtracting out the costs associated with (for instance) a power purchase agreement. As described in more detail below, LSSP technologies provide 3.7-10.2 cents/kWh of incremental value over and above the 20-year MPR value calculated for a 2009 baseload MPR resource type.[7]

---

[6] California Public Utilities Commission, December 18, 2008, p. 25.

[7] California Public Utilities Commission, December 18, 2009, p. 1.

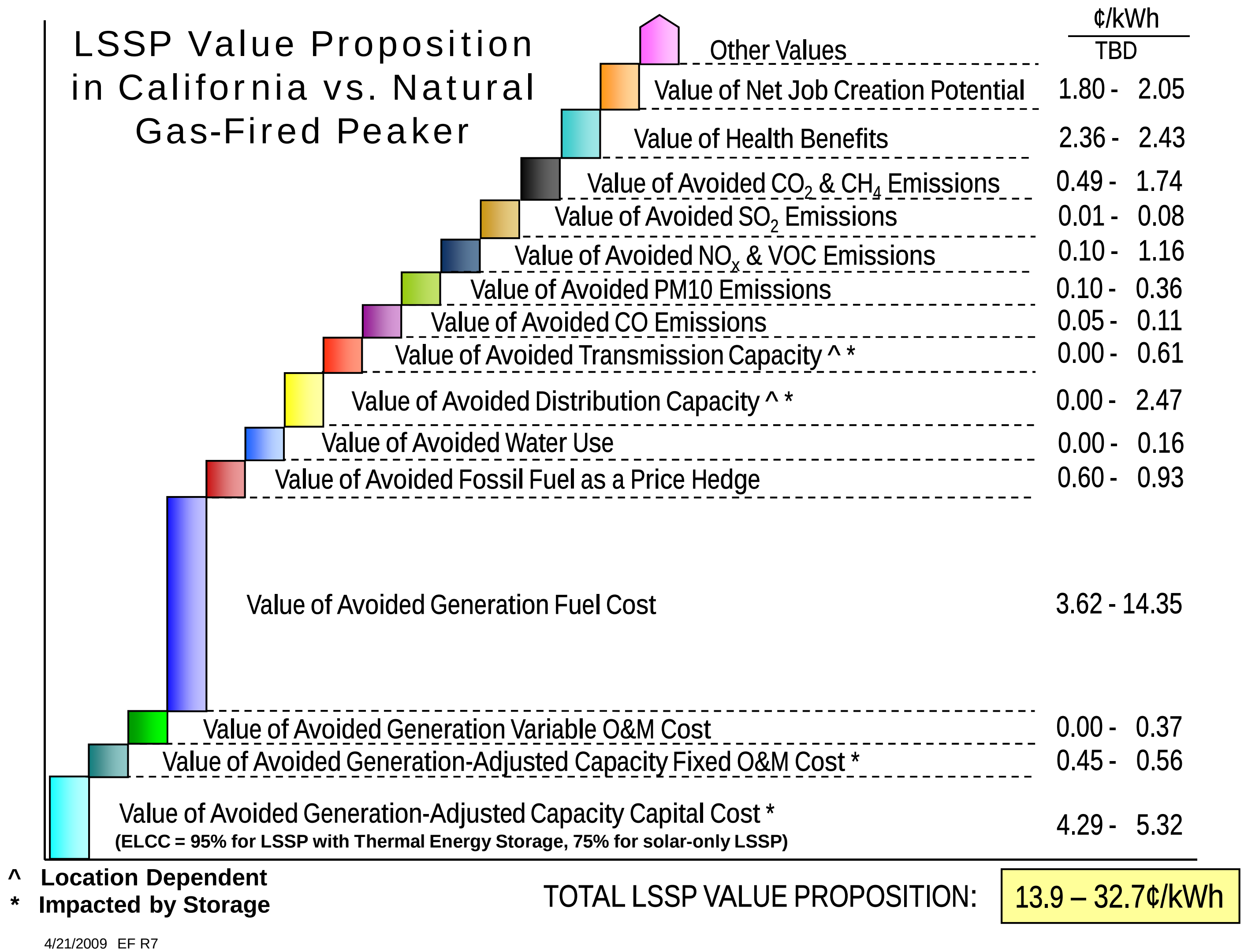

Figure 1. LSSP Value Proposition in California vs. Natural Gas-Fired Peaker

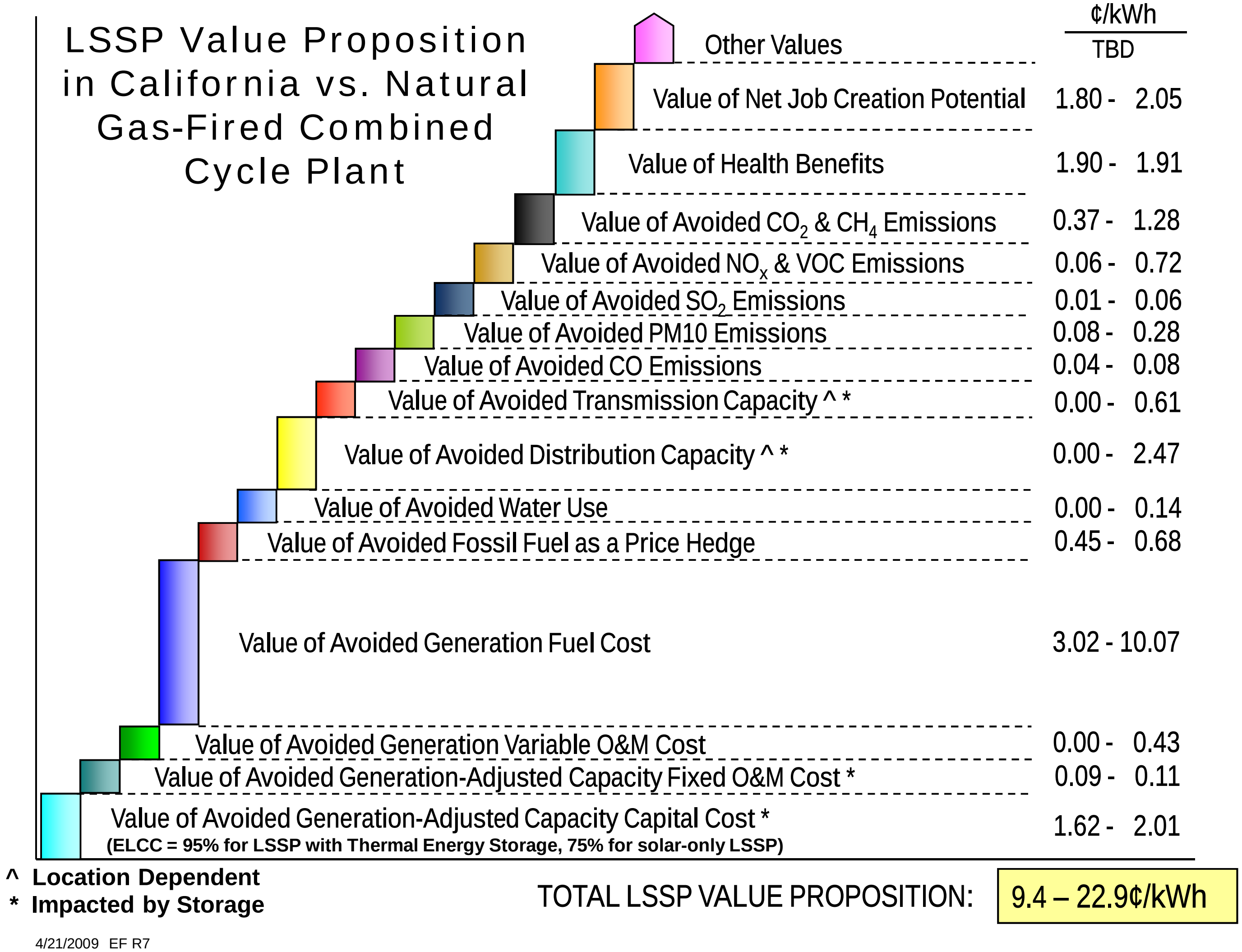

Figure 2. LSSP Value Proposition in California vs. Natural Gas-Fired Combined Cycle Plant

II. LSSP INSTALLED CAPACITY IN CALIFORNIA: CURRENT AND PROJECTED TO 2020

California has 354 MW of parabolic trough plants that have been operating since the 1980s. There are pending applications (or approvals) for approximately 4,500 MW of large-scale solar thermal electric projects and 800 MW of large-scale solar PV projects filed with the California Energy Commission ("CEC"), with projected on-line dates ranging from 2009-2013.[8] In addition, significant quantities of land have been reserved for proposed solar projects that have not yet filed applications with the CEC.

There have been numerous studies to estimate the potential for LSSP in California, given the state's significant solar resource. The California Renewable Energy Transmission Initiative ("RETI") identified 1,785 large-scale solar project sites in California in its initial screen, which it narrowed down to 326 project sites based on economic and site screening. These 326 projects could result in 65,000 MW of potential in-state thermal electric generating capacity (200 MW in size) or 48,900 MW of large-scale PV projects (150 MW in size).[9] Navigant Consulting projected U.S. total installations of LSSP through 2016 (including California's 65% share of the U.S. total) by solar technology generating type, anticipating the recent eight-year extension of the federal Investment Tax Credit ("ITC") under the Economic Stabilization Act of 2008.[10] The projected 2020 California LSSP installed capacity used in this analysis is approximately 10,000 MW, equal to 15-20% of the screened potential identified by RETI.

The 10,000 MW of 2020 California LSSP installed capacity used in this analysis relies on industry estimates in conjunction with the Navigant Consulting growth projections for LSSP. This analysis assumes (i) 75 percent of the Navigant Consulting growth projections for thermal electric technologies through 2016,[11] with flat growth from 2017-2020, and (ii) Navigant Consulting's "Conservative, Current ITC" growth projections for utility-scale PV technologies, with 20% growth from 2017-2020.[12] These

---

[8] The California Energy Commission's list of "Large Solar Energy Projects" can be found at http://www.energy.ca.gov/siting/solar/index.html.

[9] Renewable Energy Transmission Initiative, January 2009, pp. 6-15 – 6-17 (solar thermal) and pp. 6-24 – 6-25 (distributed and large-scale PV).

[10] Navigant Consulting, September 15, 2008, Sections 2 and 4. Note that this analysis uses 65% for California's share of the U.S. total LSPP installed capacity. Navigant Consulting differentiates between thermal electric and PV systems and assumes that California's share of U.S. total installed capacity will be 65% for PV systems (p. 19) and 72% for thermal electric systems (p. 59).

[11] Navigant Consulting, September 15, 2008, p. 58 (thermal electric) and p. 17 (large-scale PV).

[12] Navigant Consulting, September 15, 2008, p. 6, defines "Current ITC" as being an eight-year extension of the 30% federal ITC for residential systems (capped at $2000) and commercial systems. At p. 18, the "Conservative Scenario" reflects a "longer time to pass ITC, longer time for economy to recover, tighter

assumptions result in projected 2020 California installed thermal electric capacity of 7,285 MW and large-scale PV capacity of 2,641 MW, for a total of 9,926 MW of LSSP.[13]

Half of the 7,285 MW of 2020 California installed thermal electric capacity is assumed to have solar-only operations and the other half is assumed to have integrated TES. Assuming a solar-only annual capacity factor of 25% and an annual capacity factor of 40% for thermal electric operations with TES, an average annual capacity factor of 37.5% is assumed for aggregate 2020 thermal electric system operations; this compares to an assumed aggregate average annual capacity factor of 22% for PV systems. The combined 2020 installed LSSP capacity projections and associated aggregate average annual capacity factors are used in this analysis to estimate 2020 natural gas savings, emissions reductions, and job creation potential.

III. LSSP CONTRIBUTION TO AB 32 EMISSIONS REDUCTION GOALS

If the projected California installed LSSP capacity of nearly 10,000 MW in 2020 is achieved, LSSP will contribute between 12.3-16.7 million metric tonnes of carbon dioxide (“CO_2”) reductions toward the AB 32 overall goal of 172 million metric tonnes, depending on the assumed mix of avoided generating technologies.[14] These CO_2 emissions reductions will be accomplished through the avoided combustion of natural gas, given a projected natural gas savings of 229-231 million MMBtu in 2020 attributable to solar-generated electricity from the nearly 10,000 MW of projected LSSP installed capacity in California, again depending on the assumed mix of avoided generating technologies. A detailed derivation of each of the avoided emissions per kWh (and associated value) attributable to electricity generated by LSSP projects is provided below.

IV. INTRODUCTION TO AVOIDED COST VALUATION METHODOLOGY

This section will describe the details and assumptions behind the cents/kWh avoided cost values derived in the “LSSP Value Proposition in California” waterfall charts, as illustrated above in Figure 1 and Figure 2. Some of the avoided costs are quantified based on observable market prices and some are quantified based on values that are derived from a broad-based literature search. In general, the avoided costs based

money, less desire to assume risk, higher module prices, continued strong demand in Europe making modules scarce, more robust substitutes” and was deemed to better reflect the current economic situation than the alternative “Accelerated Scenario.”

13 This projected 2020 California installed LSSP capacity is approximately 90% of the 2020 estimate included in the Center for Energy Efficiency and Renewable Technologies’ projection of California’s generation mix under a 33% Renewable Portfolio Standard (February 2009, p. 6).

14 The lower number represents avoided CO_2 emissions compared to the average California natural gas-fired generating fleet and the higher number represents avoided CO_2 emissions compared to a natural gas-fired peaker.

on observable market prices are more widely accepted than are the “non-market” values derived for those value components that do not have an observable market price. For the benefit of the reader, descriptions of the underlying assumptions are provided below for each value component for which a calculated cents/kWh value range is calculated.

The range of values for each of the value components included in the two “LSSP Value Proposition in California” waterfall charts is based on the avoided costs of the two central station generating technologies potentially avoided by solar-generated electricity, *i.e.*, a natural gas combined cycle plant or a natural gas-fired peaker. The cumulative range of value for LSSP in California is calculated to be 13.9-32.7 cents/kWh for LSSP systems (with TES, where applicable) when the avoided generator is a natural gas-fired peaker and 9.4-22.9 cents/kWh when the avoided generator is a natural gas combined cycle plant.

The incremental value of having 3-6 hours of TES integrated into LSSP plants is that the solar-generated electricity becomes dispatchable during periods of cloud cover or during hours when there would be insufficient sunlight to generate electricity using solar-only operations. This added value is limited to those value components whose calculation is affected by the on-peak availability of the solar-generated electricity, those being avoided generation capacity and operating and maintenance (“O&M”) costs and avoided T&D costs. The value components affected by the presence or absence of TES are noted by an asterisk in Figure 1 and Figure 2. As stated at the outset, this report is intended to quantify the benefits provided by LSSP plants, and does not consider solar technology costs or power purchase agreement costs.

A. AVOIDED GENERATION FUEL-RELATED COSTS

Electricity generation by LSSP systems could be valued at the avoided real-time cost of electricity on at least an hourly basis or by the applicable avoided time-of-use electricity tariff rates. However, a valuation using either of those methods does not allow identification and quantification of all of the separate value components represented in Figure 1 and Figure 2. In this analysis, the avoided cost of electricity is approximated by the Value of Avoided Generation Fuel Cost of the avoided natural gas-fired peaking generator in the first instance and of the avoided natural gas-fired combined cycle generator in the second instance. As associated Value of Avoided Fossil Fuel as a Price Hedge is also calculated for each avoided generator to reflect the value that fossil fuel-free LSSP technologies provide in avoiding exposure to volatile natural gas prices.

1. Value of Avoided Generation Fuel Cost

LSSP technologies rely solely on sunlight to generate electricity, with the potential for TES to make the solar-generated electricity dispatchable for limited periods. Therefore, all of the fuel (and the costs thereof) required by the avoided central station generator is avoided due to the electricity generated by the LSSP systems. The avoided fuel use is determined by the heat rate of the avoided peaking generator during peak-load periods or of the average California natural gas-fired generating fleet during the intermediate-load periods. The heat rate of the average California natural gas-fired generating fleet is used for all avoided fuel and avoided emissions calculations because it is more representative of actual day-to-day grid operations than assuming that the avoided generator is always the most-efficient combined cycle plant (as reflected in the parameters for the CPUC's 2008 MPR proxy plant).

The avoided peaking generator is assumed to have a heat rate of 10,450-10,833 British thermal units ("Btu") per kWh.[15] The 2008 MPR proxy plant has a first-year adjusted heat rate of 6,879 Btu/kWh, increasing over time to a maximum heat rate of 6,932 Btu/kWh.[16] The average California natural gas-fired generating fleet had a 2002-2006 average heat rate of 7,937 Btu/kWh, about 15% higher than the average heat rate of the 2008 MPR proxy plant. A 15% upward adjustment is made to the 2008 MPR proxy plant heat rate range of 6,879-6,932 Btu/kWh to estimate an average California natural gas-fired generating fleet heat rate range of 7,907-7,967 Btu/kWh.

The range of avoided natural gas prices is determined by a monthly rolling average of daily settlement prices for prompt-month natural gas futures contracts on the New York Mercantile Exchange ("NYMEX") for the avoided average California natural gas-fired generating fleet and by the prompt-month daily settle prices for the avoided peaking unit.[17] As illustrated in Figure 3, the daily NYMEX prompt-month price range since January 2006 has been $3.80-$13.58/MMBtu and the monthly rolling average range has been $4.15-12.97/MMBtu, for natural gas located at the Henry Hub, onshore Louisiana.[18]

---

[15] U.S. Department of Energy, June 2008, Table 38, p. 79. The lower value is the nth-of-a-kind heat rate for a conventional natural gas combined cycle plant and the higher value is the 2007 heat rate for the same unit.

[16] Energy and Environmental Economics, 2008, "Heat_Rate" tab.

[17] The term "prompt month" refers to the earliest month for which futures contracts are trading. Trading of futures contracts for any given delivery month ends prior to the end of immediately previous month. Therefore, "the prompt month" in mid-April would be May, but by the end of April, after trading for the May futures contract closes, the prompt month becomes June. The monthly rolling average of daily settlement prices is based on a 22-day trading month and is used assuming that most baseload generators buy natural gas on a monthly basis; the daily settlement prices are used for the peaking unit assuming that those units buy natural gas on an as-needed basis.

[18] A negative cost adjustment of $0.33/MMBtu has been made to reflect the 10-year average projected value of transportation from the Henry Hub to California, as reflected in the fuel price for the 2008 MPR proxy plant. (*See* California Public Utilities Commission, December 18, 2008, p. 10 and Energy and Environmental Economics, Inc., 2008, "CA_Gas_Forecast" tab.) This transportation value (known as the "basis") is highly volatile, varies seasonally, and has historically had both positive and negative values from the Henry Hub to California.

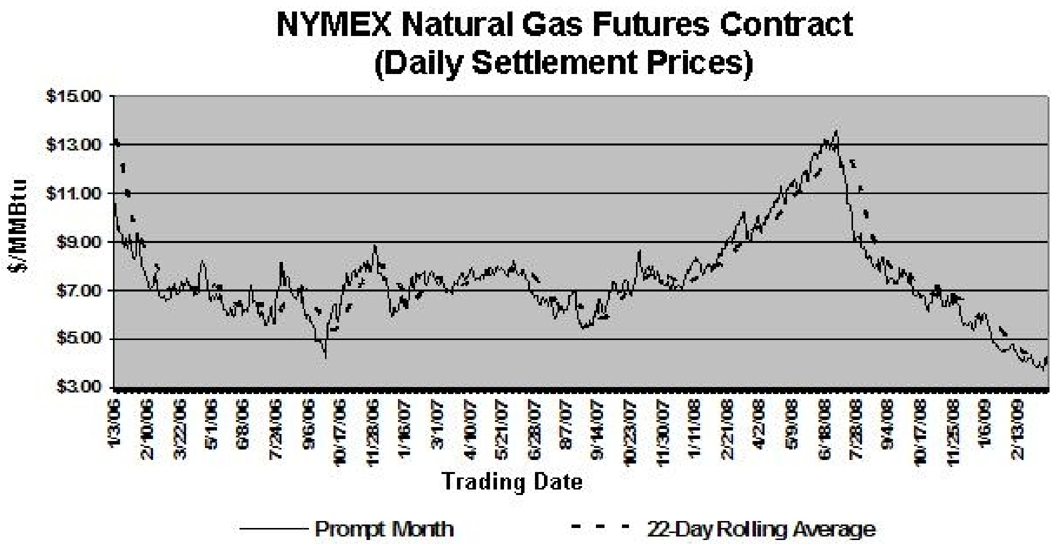

Figure 3. NYMEX Natural Gas Futures Contract, Daily Settlement Prices and 22-Day Rolling Average, 2006 Forward

The NYMEX natural gas price is converted to cents per kWh by multiplying it times the range of heat rates assumed for (i) the average California avoided natural gas-fired plant (*i.e.*, 7,907-7,967 Btu/kWh)[19] and (ii) the average avoided natural gas-fired peaking unit (*i.e.*, 10,450-10,833 Btu/kWh).

The Avoided Generation Fuel Cost values calculated using the above methodology yields a range of 3.62-14.35 cents/kWh for the avoided natural gas peaking generator and 3.02-10.07 cents/kWh for the average California avoided natural gas-fired plant.

Note that the CPUC's 2008 MPR values for use in the 2008 Renewable Portfolio Standard solicitations are based on a 2009 California natural gas price of $10.60/MMBtu.[20] If this point estimate of natural gas prices were to be used to calculate the Avoided Generation Fuel Cost values, the resultant ranges of values would be 11.08-11.48 cents/kWh for the avoided natural gas peaking generator and 8.38-8.45 cents/kWh for the avoided natural gas-fired combined cycle plant. If these ranges of values were then substituted for the ranges of values for the Avoided Generation Fuel Cost in Figure 1 and Figure 2, the resultant Total LSSP Value Proposition would be 21.3-29.8 cents/kWh

19 The average California avoided natural gas-fired plant had a five-year weighted-average heat rate for 2002-2006 that was approximately 15% less efficient than that of the 2008 proxy plant, based on state-specific electricity generation and fuel consumption values as reported by the U.S. Department of Energy at http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html for electricity generation and at http://tonto.eia.doe.gov/dnav/ng/ng_cons_sum_dcu_SCA_a.htm for natural gas consumption.

20 Energy and Environmental Economics, Inc., 2008, "CA_Gas_Forecast" tab.

against the peaking generator and 14.8-21.3 cents/kWh against the combined cycle plant. Netting out from the latter range the 20-year value of 11.119 cents/kWh for Resource Type "2009 Baseload MPR" indicates that the LSSP technologies provide to Californians an incremental value of 3.7-10.2 cents/kWh over and above the "2009 Baseload MPR" value.

2. Value of Avoided Fossil Fuel as a Price Hedge

Natural gas futures prices are notoriously volatile, as reflected in the monthly average $4.15-$12.97/MMBtu range of NYMEX prices over the past three years. Since solar energy as a fuel source is cost-free, LSSP systems provide a natural hedge that allows customers to avoid natural gas price volatility for all electricity generated by those LSSP installations. The value of this hedge is based on the market premium that one would pay to obtain fixed-price natural gas supplies over the long term, which is a more traditional means of smoothing out the volatility in natural gas prices. Utilities (or other large customers) have greater ability to meet established operating budgets because of the fuel price hedge value provided by LSSP generation.

This size of the market premium required to "lock in" fixed natural gas prices depends on long-term natural gas price forecasts and on how volatile natural gas prices are in the shorter term. Based on past market studies, LSSP systems provide Value of Avoided Fossil Fuel as a Price Hedge in the range of 0.60-0.93 cents/kWh for the avoided natural gas-fired peaking generator and 0.45-0.68 cents/kWh for the average California avoided natural gas-fired plant.[21] The range of estimates for the Value of Avoided Fossil Fuel as a Price Hedge is based on applying the heat rate ranges of 7,907-7,967 Btu/kWh and 10,450-10,833 Btu/kWh (discussed above) for the avoided generators to estimates from the previous market studies, adjusting for heat rate and price level differences.

---

[21] Bolinger and Wiser, January 7, 2008, p.8, estimated the hedge value to be 59-89 cents/MMBtu of natural gas, similar to estimates made in their previous analyses. *See*, for instance, Bolinger, *et al.*, January 2004, p. 8, where the estimated hedge value was 50-80 cents/MMBtu.

B. IMPACT ON CALIFORNIA OF AVOIDED NATURAL GAS USE

1. Impact on California Natural Gas Prices

The greater the number of LSSP systems that are installed in California, the greater will be the resultant natural gas savings. As natural gas consumption for central station electricity declines, a threshold of natural gas savings may occur such that natural gas prices in California begin to soften. Because the benefits of this price impact would predominantly occur in future years as the market penetration of LSSP in California increases, the value of this price impact associated with natural gas savings from LSSP is not included in the waterfall charts in Figure 1 and Figure 2. The discussion below outlines how this price impact could be quantified.

For discussion purposes only, the potential impact on natural gas prices is calculated based on an estimated 229-231 million MMBtu of natural gas savings in 2020 resulting from the projected 9,926 MW of 2020 LSSP installed capacity in California (discussed above). Assuming statewide natural gas demand of 2,600 million MMBtu in 2020, the 229-231 million MMBtu of natural gas savings would represent a reduction of over 8.8% of the total volume of natural gas demand in California.[22]

Economic studies have calculated that natural gas prices change from 0.8-2.0% for each 1% change in natural gas demand.[23] Therefore, an 8.8% decline in total California natural gas consumption could result in a 7-18% reduction in natural gas prices. Based on the $3.80-$13.58/MMBtu range of NYMEX prompt-month natural gas futures price range cited above, the natural gas price reduction would range from $0.27-$2.41/MMBtu. When applied to the 2,600 million MMBtu of statewide natural gas demand, the annual value to Californians of the natural gas savings attributed to LSSP would range from $0.7-$6.3 billion in 2020.

2. Impact on California Electric Prices

Since over one-third of California's electricity is generated using natural gas, changes in the price of natural gas would be expected to have a significant impact on the prices of electricity in California. The value to Californians of related reductions in electricity prices has not been quantified in this analysis, though it could be significant.

---

[22] The 2,600 million MMBtu of statewide natural gas demand is estimated based on the 2007 Integrated Energy Policy Report's 2017 projected demand of 6,800 million cubic feet per day, growing at 1% per year plus and estimated 73,000 million cubic feet per year for increased use of natural gas for transportation purposes. (*See* California Energy Commission, 2007, pp. 178-179.)

[23] Wiser, *et al.*, January 2005, p. 18.

C. AVOIDED GENERATION CAPACITY-RELATED COSTS

The avoided generation costs include separate estimates for avoided capacity-related costs and for avoided energy-related costs. This separation allows for an analysis of the individual components that go into setting the market price of electricity in the absence of a liquid electricity market with transparent prices.

1. Value of Avoided Generation-Adjusted Capacity Capital Cost

The range of the Value of Avoided Generation-Adjusted Capacity Capital Cost is calculated based on the annualized capacity value of a natural gas-fired peaking generator or of a natural gas-fired combined cycle generator. The annualized avoided capacity capital cost in each case is calculated as the annual capacity charge rate (15% from Duke, *et al*., p. 9) times the capital cost for the technology. Capital costs are estimated at $794 per kW-yr for the peaking generator[24] and $1,182 per kW-yr for the combined cycle generator, the latter based on the parameters specified for the 2008 MPR proxy plant.[25]

Since peak electricity loads are predominantly driven by air conditioning demand on sunny days, the capacity credit (avoided cost) for the LSSP technologies should be set based on the effective load carrying capacity ("ELCC") of those technologies at a certain area within the system. The ELCC is the capacity of any electricity generator to contribute effectively to a utility's capacity to meet its peak load.[26] The electricity generated by solar-only LSSP systems peaks when the sun is at its zenith, though California's peak demand usually occurs later in the afternoon, sometime between 2:00-4:00 p.m. Figure 4 shows the contribution of specific distributed generation technologies, including PV, during the 2007 peak hour for the California Independent System Operator ("CAISO"), which occurred from 2:00-3:00 p.m. on August 31, 2007.[27] The generation profile of large-scale (non-concentrating) PV systems would be similar to that of the distributed PV systems shown in Figure 4, though the main purpose of Figure 4 is to show the timing difference between the solar peak and the CAISO peak.

---

[24] Energy and Environmental Economics, Inc., May 13, 2008, "Gen Cost" tab. This capacity cost value for a peaker approximates the mid-point between the January 16, 2009, CPUC proposed decision citing Southern California Edison's recovery of $1,200/kW in capacity costs for four natural gas-fired peakers and the $250.43/kW capacity cost value used for a merchant simple cycle peaker by the California Energy Commission, December 2007, p. 7.

[25] California Public Utilities Commission, December 18, 2008, p. 25.

[26] Herig, September 2001, p. 2,

[27] Itron, Inc., September 2008, p. 1-6.

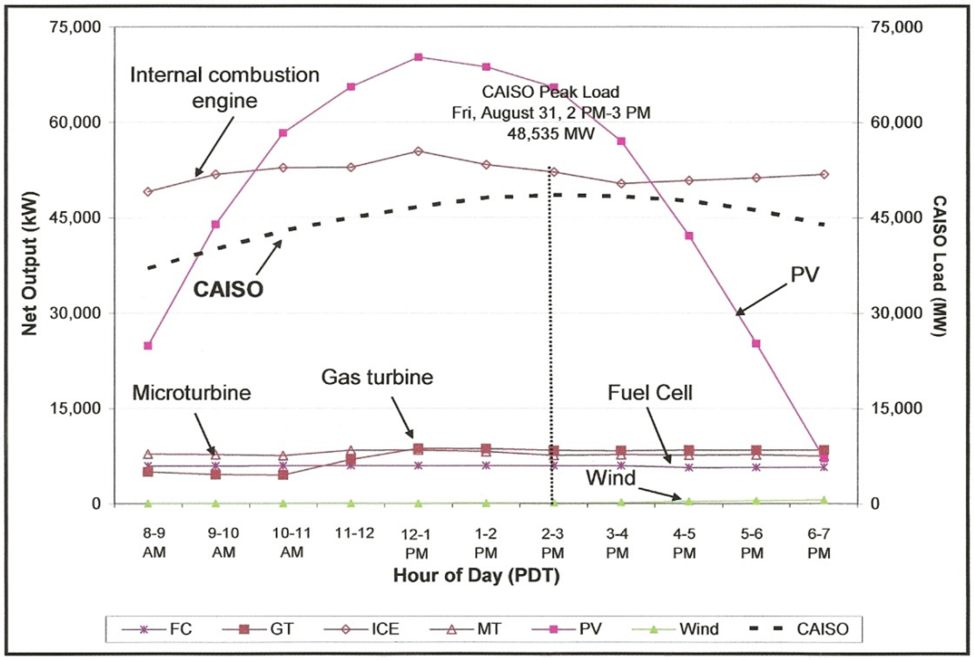

Figure 4. Self-Generation Incentive Program, Technology-Specific Capacity Contribution to California Independent System Operator Peak, 2007

The ELCC for each of the LSSP technologies included in this analysis is assumed to be 75% without TES and estimated to be 95% with TES.[28] (This can be interpreted to mean that solar-only LSSP systems are generating 75% of their full capacity at the time of the mid- to late-afternoon peak demand.) The graph in Figure 5 illustrates the portion of load provided by a solar-only LSSP system located in Nevada, in which it can be seen that greater LSSP generation is available at the solar peak (bracket "A") than is available at the time of the peak load (bracket "B"). The graph in Figure 6 shows how the addition of TES allows the same LSSP system to extend and in effect dispatch its electricity generation into the later afternoon hours. The graph in Figure 7 illustrates an alternative case in which TES is used to increase the ability of LSSP systems to provide additional on-peak capacity. By increasing the ability of LSSP systems to shift the timing of their solar-generated electricity, TES increases the applicable ELCC.

[28] Perez, *et al.*, June 2006, p. 5, provides ELCC values for California ranging from 59% for horizontal PV to 75% for two-axis tracking PV, based on 2% grid penetration. Since this analysis involves LSSP projects, many of which rely on concentrating sunlight and involve tracking mechanisms, the higher ELCC value of 75% is used for solar-only generation. As noted above, the ELCC will decline with increasing levels of LSSP penetration due to peak shifting of the demand remaining to be met by fossil fuel-fired generation.

.

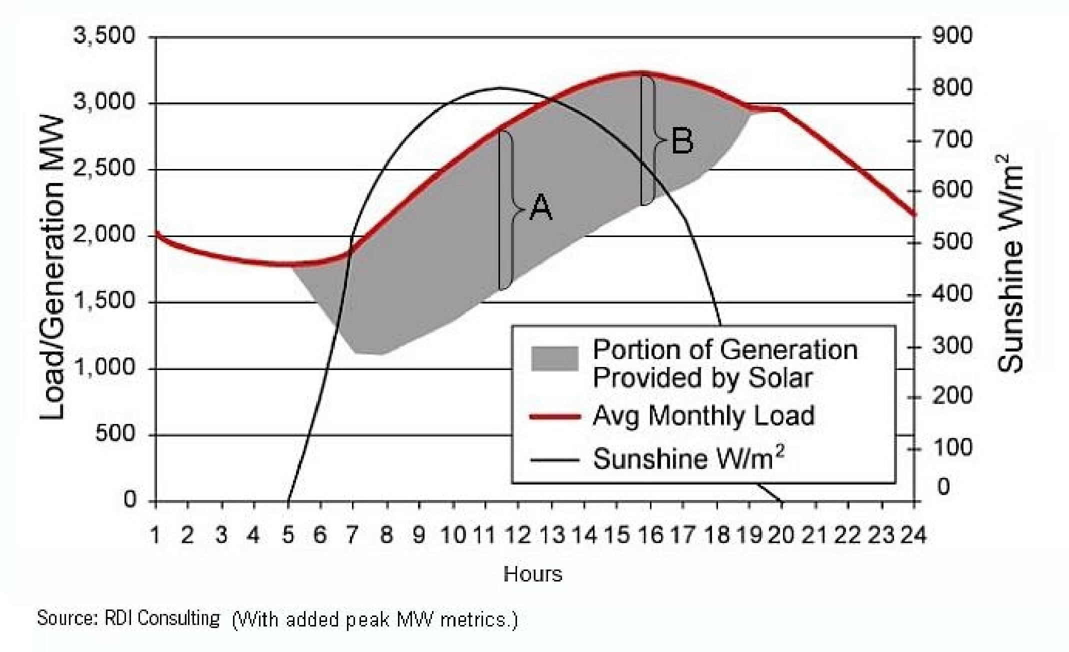

Figure 5. Illustrative Generation of a 1,250 MW LSSP Plant Without TES, Nevada Power Market Area[29]

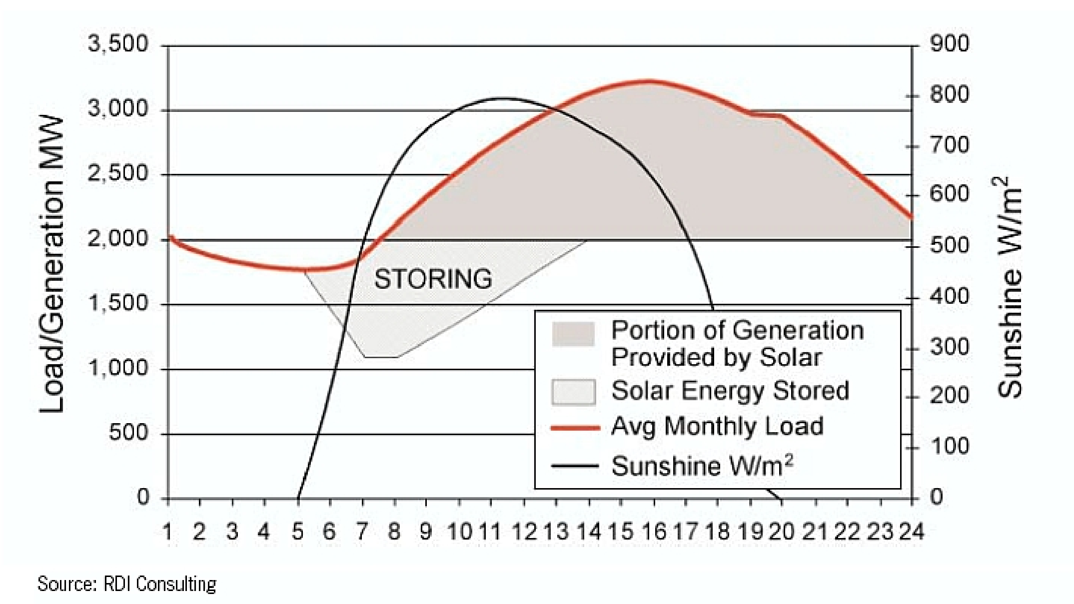

Figure 6. Illustrative Generation of a 1,250 MW LLSP Plant With TES, Nevada Power Market Area[30]

29 National Renewable Energy Laboratory, July 2002, p. 55.

30 National Renewable Energy Laboratory, July 2002, p. 56.

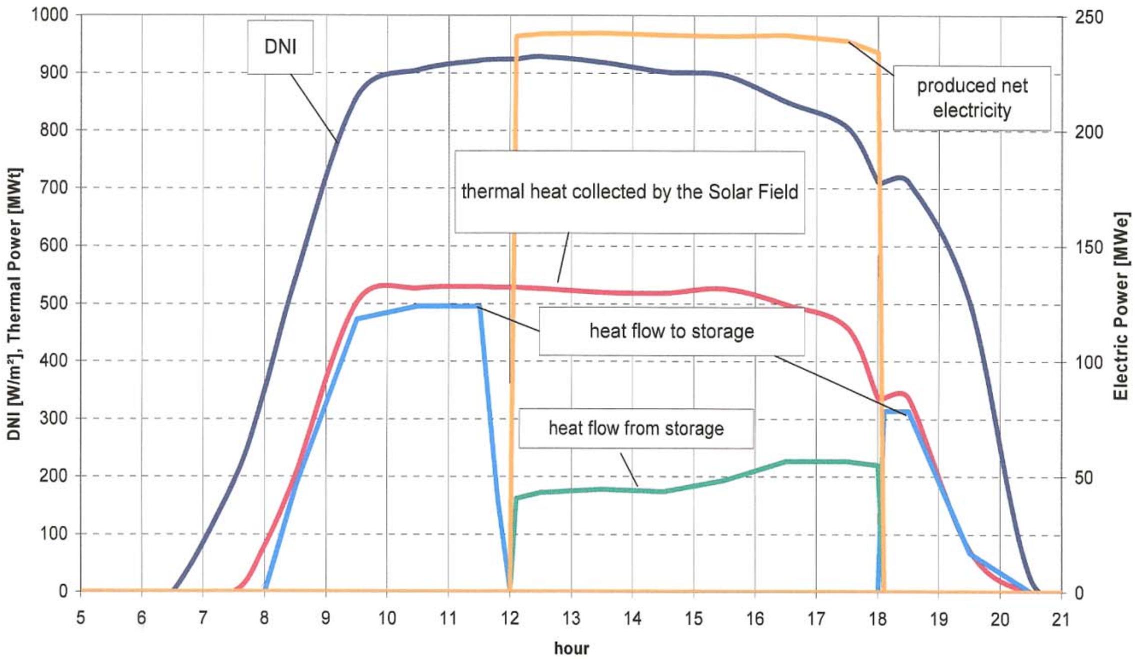

Figure 7. Illustrative Impact of TES on Ability of LSSP Systems to Provide On-Peak Capacity[31]

To account for plant availability, the applicable ELCC is adjusted to reflect the overall plant availability for each LSSP technology, which ranges on average from 96% to 98%.[32] These values are multiplied times the Avoided Generation-Adjusted Capacity Capital Cost and the Avoided Generation-Adjusted Capacity Fixed O&M Cost for the avoided central station generator to calculate the value of the capacity-related avoided costs attributable to the LSPP system. ***Note that for any given LSSP system, the capacity-related avoided costs should reflect the localized system average ELCC.***

To convert the adjusted $/kW-yr capital cost (and fixed O&M costs) to cents/kWh, it is necessary to divide the $/kW-yr values by the number of hours per year during which each avoided generating technology is expected to generate electricity; this number is derived from the average annual capacity factor for each of the avoided generating technologies. The average annual capacity factor for the avoided peaking generator is assumed to be 23.3%, or 2,041 hours per year (*i.e.*, 8760 hours/year x 0.233).[33] The annual average capacity factor for the avoided combined cycle generator is

[31] Aringhoff, Rainer, March 5, 2008, p. 7, demonstrating the shift of solar-generated electricity from a solar power tower from morning and evening hours to critical on-peak hours through the use of TES.

[32] Electric Power Research Institute, March 2007, p. 7-23; Navigant Consulting, August 2007, p. 46.

[33] This value is based on the 2004 MPR capacity factor for a natural gas peaking generator, the last year in which the CPUC specified a capacity factor for a peaking unit for purposes of calculating an MPR. *See*

assumed to be the 92% used for the 2008 MPR proxy plant, or 8,059 hours per year (*i.e.*, 8760 hours/year x 0.92).[34]

Dividing the avoided generation capacity capital cost for each avoided generating technology by its associated average annual hours of operation yields a Value of Avoided Generation-Adjusted Capacity Capital Cost of 4.29-5.32 cents/kWh for the avoided peaking generator and 1.62-2.01 cents/kWh for the avoided combined cycle generator for LSSP systems having 3-6 hours of TES. For solar-only LSSP systems, the capacity-related values are reduced by about 2% for the avoided combined cycle generator and by nearly 20% for the avoided peaking generator, based on the 20% reduction in the ELCC for LSSP systems without TES. The impact is greater for the avoided peaking generator because of its significantly higher capital cost when expressed in the cents/kWh metric used in this analysis.

The Value of Avoided Generation-Adjusted Capacity Capital cost shown in Figure 1 and Figure 2 is a snapshot based on the current market penetration levels of LSSP systems. As the market penetration of LSSP systems increases over time, LSSP systems will displace increasing amounts of natural gas-fired electricity generation during peak demand periods. This will have the effect of shifting peak demand to be met by fossil fuel-fired generation later into the evening hours; this "peak shifting" will reduce the ability of solar-only LSSP systems to provide capacity value and thereby increase the value of TES.

2. Value of Avoided Generation-Adjusted Capacity Fixed O&M Cost

This is an additional avoided generation capacity-related cost, starting with an avoided generation capacity fixed O&M cost of $12.54/kW-yr for the natural gas-fired peaking generator and $9.70/kW-yr for the combined-cycle generator, derived from the same sources as for the avoided generation capacity costs. A similar calculation to that described in the previous section yields a Value of Avoided Generation-Adjusted Capacity Fixed O&M Cost of 0.45-0.56 cents/kWh for the avoided peaking generator and 0.09-0.11 cents/kWh for the avoided combined cycle generator.

3. Value of Avoided Generation Variable O&M Cost

The Value of Avoided Generation Variable O&M Cost for each avoided generating technology is determined by that technology's residual variable O&M cost after removing the Value of Avoided Water Use. (The Value of Avoided Water Use is separated out to emphasize the value of avoiding water use in drought-prone California.)

CPUC, February 10, 2005, p. 11. The 5% capacity factor for a peaking generator used by Energy and Environmental Economics, Inc., May 13, 2008, "Gen Cost" tab, would increase the upper end of the Value of Avoided Generation-Adjusted Capacity Capital Cost in Figure 1 nearly five-fold in the cents/kWh metric used in this analysis.

[34] CPUC, December 18, 2008, p. 25.

The Value Avoided Water Use therefore sets an upper limit on the avoided variable O&M costs, as discussed in more detail below.

The variable O&M cost is assumed to be 0.370 cents/kWh for the avoided peaking generator[35] and 0.435 cents/kWh for the avoided combined cycle generator.[36] After subtracting out the range of Value of Avoided Water Use for each avoided technology, the Value of Avoided Generation Variable O&M Cost is 0.00-0.37 cents/kWh for the avoided peaking generator and 0.00-0.43 cents/kWh for the avoided combined cycle generator.

D. AVOIDED WATER USE

1. Value of Avoided Water Use

LSSP systems can be designed for very low water requirements and are increasingly designed to use dry cooling. Dish/engine and PV systems are air-cooled by design, and use water mainly for washing the mirrors and PV modules. The steam power plants driven by parabolic trough and power tower systems can utilize dry cooling technology at a modest increase in electricity cost. Parabolic trough systems have historically used wet cooling towers for cooling, with the cooling tower make-up water representing approximately 90% of the raw water consumption. Steam cycle make-up water represents approximately 8% of raw water consumption, with mirror washing constituting the remaining 2% of raw water consumption.[37] Annual water consumption at parabolic trough plants is about half that of agricultural use for an area the size of the solar field, and some other LSSP technologies use significantly less water.[38] Dry cooling can reduce raw water consumption by up to 90%, but can increase plant electricity costs by 10% or more.[39] This analysis assumes that parabolic trough and power tower systems use dry cooling, with a related 10% de-rating factor.

The Value of Avoided Water Use that electricity generated by LSSP installations provides is calculated based on avoided water consumption relative to either the avoided natural gas-fired peaking generator or an avoided natural gas combined cycle generator. The combined cycle, natural gas-fired 2008 MPR proxy plant uses dry cooling; CEC data for a similar plant indicates that only 0.0189 gallons of raw water are required per kWh of generation;[40] this value is "grossed up" (by heat rate differential) to 0.0221

---

35 Energy and Environmental Economics, Inc., May 13, 2008, "Gen Cost" tab.

36 CPUC, December 18, 2008, p. 25.

37 Western Governors' Association, January 2006, p. 15.

38 California Energy Commission, November 2005, p. 64.

39 California Energy Commission, November 2005, p. 64.

40 California Energy Commission, April 2006, p. 36.

gallons/kWh for a dry-cooled peaking generator. Closed recirculating cooling for a natural gas combined cycle plant is estimated at 0.2826 gallons/kWh, which grosses up to 0.3304 gallons/kWh for a natural gas-fired peaking generator. These values compare to an estimated range of raw water use per kWh for LSSP installations as shown in Table 1.

Table 1. Comparison of Raw Water Use for LSSP Installations

LSSP Technology	Wet Cooling Gallons/kWhe	Dry Cooling Gallons/kWhe
Parabolic Trough	0.905	0.072[41]
Dish/Engine	0.0019[42]	
Solar Power Tower	0.634[43]	0.0137[44]
Compact Linear Fresnel	0.905	0.072
Concentrating PV	0.0019[45]	
Non-Concentrating PV	0.0038[46]	

The above values indicate that dish-engine systems and PV systems avoid water use against both natural gas-fired generators for both wet and dry cooling. Wet-cooled parabolic trough, power tower, and compact linear Fresnel systems do not result in avoided water use if the avoided generator is dry-cooled. The range of water costs applied to the avoided central station water use is $0.557-$3.636 per hundred cubic feet of metered water, based on tariff rates as of March 2007 for Class A water companies located throughout California.

The calculated (unadjusted) range of Value of Avoided Water Use is 0.00-0.160 cents/kWh for an avoided peaking generator and 0.00-0.136 cents/kWh for an avoided combined cycle generator. However, the cost of water usage is typically included in a generator's variable O&M cost. Therefore, the Value of Avoided Water Use cannot

[41] California Energy Commission, November 2005, p. 48.

[42] Calculated based on specifications provided in California Energy Commission, Docket No. 08-AFC-5, for the Solar Two Project at http://www.energy.ca.gov/sitingcases/solartwo/documents/applicant/afc/volume_01/MASTER_Section%205.5.pdf

[43] SolarPaces, "Solar Power Tower" technology primer, p. 5-22, available online at: http://www.solarpaces.org/CSP_Technology/docs/solar_tower.pdf

[44] Calculated based on specifications provided in California Energy Commission, Docket No. 07-AFC-5, for the Ivanpah Solar Electric Generating System at http://www.energy.ca.gov/2008publications/CEC-700-2008-013/CEC-700-2008-013-PSA.PDF.

[45] CPV system water use is based on dish/engine water use, since both systems use water primarily to wash mirrors/solar modules.

[46] Based on CPV system water use, doubled to reflect the larger solar module area required by non-concentrating PV systems.

exceed the generator's Value of Avoided Generation Capacity Variable O&M Cost. In this analysis, this constraint was not an issue. Consequently, both the (adjusted) Value of Avoided Water Use of 0.00-0.160 cents/kWh for an avoided peaking generator and of 0.00-0.136 cents/kWh for an avoided combined cycle generator are the same as the unadjusted values. Each of these values has been subtracted from the values derived for the associated avoided generator in the Value of Avoided Generation Capacity Variable O&M Cost category to avoid double counting.

Note that the Value of Avoided Water Use varies significantly depending on location. In addition, commercial prices for water will underestimate the Value of Avoided Water Use to the extent that those prices do not fully reflect the societal cost of the water used.

E. AVOIDED T&D COSTS

The potential value of avoided T&D costs depends on the specific location of the LSSP system on the electric grid, as noted in the waterfall graphs in Figure 1 and Figure 2. Because of their scale and associated land use requirements, LSSP systems typically interconnect to the electric grid at transmission-level voltages, in which case there are no avoided T&D costs; the lower end of the value range for both the Value of Avoided Transmission Capacity and the Value of Avoided Distribution Capacity is consequently set to zero. However, depending on size and technology, LSSP systems may be located anywhere on the electric grid, *i.e.*, on the high voltage transmission system, on the lower voltage distribution system, or even on the site of a large electricity consuming customer. Those LSSP projects located on the distribution system have a potential Value of Avoided Transmission Capacity, and on-site LSSP projects have an additional potential Value of Avoided Distribution Capacity.

To adequately capture the potential value of avoided T&D costs attributable to LSSP systems placed at various locations on the electric grid, the upper end of the range of avoided transmission costs is calculated separate and distinct from the upper end of the range of avoided distribution costs; both are taken from the E3 Avoided Cost Study, and have been (i) adjusted to reflect the assumed California average ELCC of 95% and average availability of 98% for LSSP systems with TES and (ii) converted to cents/kWh using the average annual capacity factor of 37.5% applicable to LSSP systems with TES.[47]

1. Value of Avoided Transmission Cost

Depending on location, the Value of Avoided Transmission Cost for an LSSP system ranges from a low of zero to a high of 0.61 cents/kWh for transmission capacity into the service territory of Southern California Edison ("SCE"). The upper end of the Value of Avoided Transmission Cost of 0.61 cents/kWh is calculated by multiplying the

[47] *See* Appendix A, Table A-1 for technology-specific annual average capacity factors.

maximum 2009 E3 avoided transmission cost of $21.44/kW-yr[48] times the 95% ELCC and 98% availability and dividing it by 3,285 hours per year (= 8760 hours/year x the 37.5% average annual capacity factor).

It should be noted that the maximum 2009 E3 avoided transmission cost of $21.44/kW-yr is relatively low, based on a recent survey of analyses of the cost of new transmission required to bring renewable energy supplies to market.[49] For California-specific analyses, the estimated cost of new transmission ranged from $90-$1230/kW of incremental generation capacity. Applying the 0.15 annual capacity charge discussed above to these estimates, the annualized cost of new transmission capacity would be $13.50-$184.50/kW-yr, or $13.50-$81.00/kW-yr if the high-end cost-outlier of $1230/kW is replaced by the second-highest estimate of $540/kW. Thus, the upper end of the Value of Avoided Transmission Capacity could be nearly four times greater than the value based on the E3 Avoided Cost Study that is shown in Figure 1 and Figure 2.

2. Value of Avoided Distribution Cost

Depending on location, the Value of Avoided Distribution Cost for an LSSP system ranges from a low of zero to a high of 2.47 cents/kWh within the service territory of San Diego Gas & Electric ("SDG&E"). The upper end of the Value of Avoided Distribution Cost of 2.47 cents/kWh is calculated by multiplying the maximum 2009 E3 avoided distribution cost of $87.21/kW-yr[50] times the 95% ELCC and 98% availability and dividing it by 3,285 hours per year (= 8760 hours/year x the 37.5% average annual capacity factor).

F. NET JOB CREATION POTENTIAL

LSSP systems have local and statewide economic developmental benefits because long-term fuel costs associated with conventional electricity generation (*e.g.*, natural gas) are replaced with operations and maintenance costs (*i.e.*, labor). Much of the money that would otherwise be spent on monthly fuel costs is instead spent on LSSP-related salaries.[51]

There are three significant cycles of job creation potential associated with LSSP systems: (i) Operations and maintenance; (ii) construction; and, (ii) manufacturing. Construction of LSSP systems typically lasts for 12-36 months, and large numbers of workers are employed during the construction period. The operations and maintenance of LSSP systems creates more-limited but longer-term employment opportunities for

---

48 Energy and Environmental Economics, Inc., October 25, 2005, p. 136.

49 *See* Mills, *et al.*, February 2009, p. 23.

50 Energy and Environmental Economics, Inc., October 25, 2005, p. 136.

51 U.S. DOE, February 2007, p. v and p.15.

every LSSP system that is constructed in California. Manufacturing also creates long-term employment opportunities, and these opportunities depend on a favorable investment climate and increase as more and more LSSP systems are installed statewide.

1. Operations and Maintenance

The Value of Net Job Creation Potential of 1.80-2.05 cents/kWh shown in Figure 1 and Figure 2 is calculated based solely on the ongoing operations and maintenance-related jobs created by LSSP systems in California, net of operating jobs that might be lost as a result of (i) reduced electricity generation by the avoided natural gas-fired generators and (ii) the production and delivery of avoided natural gas use. The Value of Net Job Creation directly reflects the benefits of long-term increased in-state employment due to the increased market penetration of LSSP systems that avoid natural gas use. The Aggregate annual installations of LSSP systems in California are estimated through 2020 based on the following assumptions:

- California will have nearly 10,000 MW of LSSP installed capacity by 2020, based on the LSSP growth assumptions described earlier in this report.
- Labor costs are for ongoing operations are estimated at $49.95/hour.[52]
- Each MW of LSSP installed capacity creates 0.848 full-time equivalent ("FTE) jobs, including 0.348 direct jobs, 0.116 indirect jobs, and 0.384 induced jobs.[53] [54]
- Each MW of LSSP installed capacity results in the loss of 0.256 FTE jobs in the natural gas sector, including 0.183 total jobs in the natural gas-fired generating sector and 0.073 total jobs in the natural gas production and delivery sector.[55]

[52] $49.95/hour is based on the average statewide median annual wages for an experienced and an entry-level solar designer or engineer ($50,000-$83,200/year), assumed to carry a 50% burden rate. The range of experience is meant to reflect the operating staff experience level, and the resultant average annual wages of $66,600/year is nearly identical to the annual average for all employees in computer and electronic manufacturing in California. *See* California Statistical Abstract, Table H-4. The 50% burden rate is meant to represent the cost of employee benefits and office support staff.

[53] National Renewable Energy Laboratory, JEDI Solar Model, Version CSP1.08.02a; estimates derived for a 250 MW parabolic trough plant. (The previous version CSP1.08.02 of the JEDI Solar Model estimated 0.50 direct jobs, 0.16 indirect jobs, and 0.47 induced jobs per MW for operations at a 100 MW parabolic trough plant.) In November 2001, the Electric Power Research Institute ("EPRI") identified 80 solar thermal jobs (p. 8-13) for the 354 MW of solar thermal capacity in California (p. A-31), implying 0.226 operations jobs/MW of LSSP capacity in California in 2001. However, EPRI's report does not provide sufficient detail to enable a direct comparison with NREL's Solar JEDI Model.

[54] Most estimates of PV jobs/MW are based on installations of small-scale (*e.g.*, 2-3 kW) residential PV installations. *See*, for instance, Environment California Research & Policy Center, January 2009 (p. 7) and Renewable Energy Policy Project, November 2001 (p. 3). No distinction between LSSP technologies is made for the purposes of calculating the Value of Job Creation Potential in this analysis.

[55] CALPIRG Charitable Trust, June 2002, p. 16, reports 0.0.04 direct jobs/MW and 0.06 indirect jobs/MW for natural gas-fired generating technology operations. This jobs number is grossed up using the

The operations and maintenance-only Value of Net Job Creation Potential is calculated by dividing the total labor cost for operation of LSSP systems in a given year by the kWh generated by those same LSSP systems in that year, calculating each year's value separately through 2020.

2. Construction

The construction-related Value of Net Job Creation Potential ranges from 6.08-154.60 cents/kWh, driven by the up to three-year construction cycle, the 10.01 (net) direct, indirect, and induced FTE jobs, and the annual MWh generated by LSSP systems in each of those three years of construction.[56] The low end of the construction-related Value of Net Job Creation Potential reflects the steady-state period of growth beyond 2012 and the high end of the range reflects the large number of LSSP projects currently under construction prior to recognition of the associated MWh of (future) electricity production. The hourly rate for construction workers is estimated to be 135% that of operations workers, based on the national ratio of hourly earnings in construction vs. in trade, transportation, and utilities.[57] The construction-related Value of Net Job Creation Potential is not included in Figure 1 and Figure 2.

3. Manufacturing

Note that if new LSSP manufacturing capacity is brought to California as the penetration rate of LSSP systems increases, the future Value of Net Job Creation Potential would be even higher than calculated above due to the employment value of the manufacturing process. The manufacturing Value of Net Job Creation Potential is estimated to add up to 2.47 cents/kWh, based on the following assumptions:

- Manufacturing plants with 100 MW per year of manufacturing capacity will be added once the annual volume of LSSP systems installed in California reaches four times that size.

LSSP-related direct and indirect jobs multiplier (based on NREL's JEDI Solar Model Version CSP1.08.02a) to estimate total direct, indirect, and induced FTE jobs lost of 0.183 jobs/MW. CAL PIRG also reports 0.03 direct jobs related to natural gas extraction and transportation; this jobs number is grossed up using the LSSP-related direct jobs multiplier to estimate total direct, indirect and induced FTE jobs lost of 0.073 jobs/MW.

[56] The 10.01 (net) direct, indirect, and induced FTE jobs is calculated based on 5.41 direct jobs + 1.93 indirect jobs for LSSP-related construction (from NREL's JEDI Solar Model, Version CSP1.08.02a), minus CALPIRG's 0.49 direct jobs + 0.53 indirect jobs lost in the natural gas sector, grossed up using the LSSP-related direct and indirect jobs multiplier (based on NREL's JEDI Solar Model, Version CSP1.08.02a).

[57] U.S. Bureau of Labor Statistics, Historical Hours and Earnings, Table B-2.

- Each MW of LSSP manufacturing capacity adds 4.12 new FTE jobs (direct, indirect, and induced).[58] Note that no manufacturing job losses in the natural gas sector are assumed since many thermal electric systems use the same steam- and turbine-generator-related equipment as the avoided generating technologies.

- The average labor cost for manufacturing production workers (grossed up by 50%) is $54.95/hour, equal to 110% of the average labor cost of hourly earnings in trade, transportation, and utilities.[59]

Note that the manufacturing-related Value of Net Job Creation Potential of up to 2.47 cents/kWh is not included in Figure 1 and Figure 2. Thus, to the extent that additional LSSP manufacturing capacity can be brought into California, the upper end of that value reflected in Figure 1 and Figure 2 could be more than doubled.

It should be noted that the value of these job-related economic benefits are based on wages paid for employment related to LSSP generating plants, net of lost wages related to the avoided natural gas-fired generating plants. A more accurate metric of the value of increased employment to Californians would be the increase in the Gross State Product or net income of the state. However, calculation of these metrics would require use of an economic input-output model, which was beyond the scope of this study. The Value of Net Job Creation Potential could be significantly different than the values calculated here, given its dependence on the specific types of jobs created, local wage rates, and the actual increase in LSSP market penetration in California in the coming years.

G. AVOIDED EMISSIONS AND RELATED HEALTH BENEFITS

None of the LSSP technologies included in this analysis have any generation-related emissions. Therefore, the LSSP technologies avoid all emissions associated with the two avoided natural gas-fired generating technologies. Due to the decision made in this analysis to separate the capacity value of electricity generation from its energy value, it is necessary to consider separately attributes that would be reflected in the market value of electricity in California that are neither capacity- nor fuel-related.

Natural gas is typically the marginal fuel source that sets the market price of electricity in California, and we have assumed that the avoided generator for LSSP installations is either a natural gas-fired peaking unit or a natural gas combined cycle plant. Natural gas as the avoided generation fuel cost thus acts as a surrogate for the market price of electricity. However, since NYMEX natural gas futures contract prices

[58] National Renewable Energy Laboratory, JEDI Solar Model, Version CSP1.08.02a, calculated by adding "Manufacturing Sector Only" direct jobs and a proportionate share of indirect and induced jobs.

[59] U.S. Bureau of Labor Statistics, Historical Hours and Earnings, Table B-2, yields a 110% ratio of manufacturing to trade, transportation, and utilities hourly earnings.

do not include the cost of emissions allowances, the value of avoided emissions must be calculated separately for each of the avoided emissions identified.

To calculate the value of avoided emissions related to LSSP installations, it is first necessary to identify *for each pollutant* (i) the emissions rate in pounds per million Btu ("lb/MMBtu") of natural gas applicable to the avoided generating technology and (ii) the resultant emissions rate in lb/MWh over the assumed heat rate range for both the natural gas-fired peaking unit and for the average California avoided natural gas-fired plant. The resultant emissions rate range for the two potentially avoided generating units is the relevant range of avoided emissions, given that LSSP installations have no generation-related emissions. The minimum and maximum amount of physically-avoided emissions in lb/MWh are then valued at the end points of a range of emissions allowance prices to determine the value of each type of avoided emissions in cents/kWh.

The underlying assumptions and results for the avoided emissions and related health benefits are summarized in Attachment A. The Value of Avoided CO_2 Emissions attributed to LSSP installations in California is calculated to be 0.49-1.73 cents/kWh for the avoided peaking generator and 0.37-1.27 cents/kWh for the avoided average California natural gas-fired generator. The combined value of all other avoided emissions is 0.27-1.71 for the avoided peaking generator and 0.19-1.15 cents/kWh for the avoided average California natural gas-fired generator. Assuming that the Value of Health Benefits associated with avoided emissions is not reflected in emissions allowance prices,[60] the additional Value of Health Benefits is calculated to be 2.36-2.43 cents/kWh for the avoided peaking generator and 1.90-1.91 cents/kWh for the avoided average California natural gas-fired generator. Specific details for each avoided pollutant and related health benefits are discussed below.

1. Value of Avoided CO_2 Emissions

Although CO_2 and other GHG emissions are not yet subject to mandatory regulation in the United States, there is increasing pressure for the implementation of some type of carbon regulation, particularly on the transportation and electric utility sectors of the economy. The CPUC in 2005 began requiring the investor-owned utilities that it regulates to "penalize" potential new generation resources with an \$8/ton CO_2 cost (escalating at 5% per year) for resource planning and bid evaluation, and CO_2 markets in Europe have traded anywhere from €2-€35/metric tonne since October 2005.[61] The 2008 MPR includes a CO_2 adder of \$5/ton (\$2007) starting in 2010, escalating to \$15/ton (\$2007) in 2013.[62]

[60] Inclusion of this value component in the analysis is subject to debate. In an efficiently operating market for emissions allowances, the Value of Health Benefits would be included in the price of the emissions allowances. However, current markets for emissions allowances in California are relatively thinly traded and likely do not (fully) reflect the Value of Health Benefits associated with the avoided emissions attributed to LSSP plants.

[61] Chicago Climate Exchange, various dates.

[62] California Public Utilities Commission, December 18, 2008, p. 25.

For natural gas-fired generators, the Updated E3 Electric Avoided Costs Workbook estimates a linear relationship between CO_2 emissions and plant heat rate between a heat rate floor of 6,240 Btu/kWh and a heat rate ceiling of 14,000 Btu/kWh, with a carbon intensity of natural gas of 117 pounds CO_2 per MMBtu.[63] Based on the 7,907-7,967 Btu/kWh heat rate range assumed for the average California avoided natural gas-fired plant in this analysis, the associated CO_2 emissions rate would be 0.46-0.47 ton/MWh. The CO_2 emissions rate for the avoided natural gas-fired peaking unit is estimated to range from 0.61-0.63 ton/MWh over the assumed heat rate range of 10,450-10,833 Btu/kWh. Given the absence of generation-related LSSP emissions, all of these CO_2 emissions are avoided by LSSP generation.

The CPUC's initial assumed value of $8.00/ton CO_2 is used to establish the minimum Value of Avoided CO_2 Emissions.[64] The maximum price per ton of CO_2 is more difficult to assess, with the European prices mentioned above being the only real source of existing market data. If the maximum European price of €35/metric tonne is converted to $/ton using a historical range of $0.85-$1.35/€, the resultant range of CO_2 emissions allowance prices is $27.00-$41.87/ton CO_2.

In terms of carbon, rather than of CO_2, the CPUC's required use of $8/ton of CO_2 in the IRP process is the equivalent of $29.33/ton of carbon. This is in contrast to the $100/ton of carbon assumed in Duke, *et al.*, p. 9, which is the equivalent of $27.27/ton of CO_2. A cost of $27.27/ton of CO_2 is applied to the upper end of the range of avoided CO_2 emissions and a cost of $8/ton of CO_2 is applied to the lower end of the range of avoided CO_2 emissions for each avoided generating technology.[65] The resultant range of Value of Avoided CO_2 Emissions is 0.49-1.73 cents/kWh for the avoided peaking generator and 0.37-1.27 cents/kWh for the avoided average California natural gas-fired generator.

2. Value of Avoided Methane (CH_4) Emissions

It is estimated that 1.4% of gross natural gas production is lost to the atmosphere as fugitive emissions during natural gas "extracting, processing, transmitting, storing, and distributing."[66] Avoiding natural gas use through the use of LSSP technologies therefore

---

[63] *See* Updated E3 Electric Avoided Costs Workbook supporting file cpucAvoided26-1_update3-20-06.xls for detailed derivation.

[64] Energy and Environmental Economics, Inc., October 25, 2004, provides the supporting documentation for the Updated E3 Electric Avoided Costs Workbook; its calculations use a cost estimate of $0.004/lb of CO_2, which is the equivalent of the $8/ton of CO_2 penalty applied in the CPUC's Integrated Resource Planning process.

[65] Any change to the assumed CO_2 cost would result in a proportionate change to the Value of Avoided CO_2 Emissions, *i.e.*, doubling the upper end of the CO_2 cost range would double the upper end of the Value of Avoided CO_2 Emissions value range.

[66] Spath and Mann, February 2001, pp. 8-9.

avoids this amount of fugitive natural gas emissions. Natural gas is 75-95% methane[67] and methane "is 21 times as potent as CO_2 as a global warming pollutant."[68] These factors are applied to the physical natural gas savings attributable to LSSP technologies from the avoided natural gas-fired generators at the $8-$27.27/ton CO_2-equivalent emissions cost range used above. The result is an additional Value of Avoided Methane (CH_4) Emissions of up to 0.013 cents/kWh.

3. Value of Avoided NO_x Emissions

For the average avoided California natural gas-fired plant, the NO_x emissions rate is calculated using the Updated Energy and Environmental Economics, Inc. ("E3") Electric Avoided Costs workbook.[69] Using the average avoided natural gas-fired plant's assumed heat rate range of 7,907-7,967 Btu/kWh, the resultant NO_x emissions rate is approximately 0.10 lb/MWh. The avoided natural gas-fired peaking unit is assumed to have a heat rate range of 10,450-10,833 Btu/kWh, with a resultant NO_x emissions rate range of 0.17-0.18 lb/MWh. Since LSSP technologies have no generation-related emissions, all of the NO_x emissions from the avoided generating units are avoided.

The value of the avoided NO_x emissions is based on observed prices for Emissions Reduction Credits ("ERCs") bought and sold in California. These NO_x ERCs are bought once for the life of the emissions permit, and are priced in $/lb/day. The range of prices used is this analysis is $47,000-$374,384/lb/day.[70]

Combining the calculated range of avoided NO_x emissions and the applicable range of prices for each of the avoided generating technologies considered in this analysis yields a range of values of avoided NO_x emissions of 0.09-0.76 cents/kWh for the avoided peaking generator and 0.05-0.42 cents/kWh for the avoided average California natural gas-fired generator.

4. Value of Avoided SO_2 Emissions

The Updated E3 Electric Avoided Costs Workbook does not include calculations of SO_2 emissions, but the California Environmental Protection Agency ("Cal EPA") in its California Hydrogen Blueprint estimates SO_2 emissions from a natural gas combined

---

67 Spath and Mann, February 2001, p. 8. The Value of Avoided Methane (CH_4) Emissions is calculated based on methane having a density of 0.717 kg/m^3 (Wikipedia) and making up 75% of total the energy content of natural gas.

68 California Air Resources Board, October 2008, p. 194.

69 Energy and Environmental Economics, Inc., March 20, 2006.

70 All emissions prices used in this analysis are based on Market Price Index ranges reported online by CantorCO2e Environmental Brokerage. For consistency, the ERC prices referenced in this analysis have all been converted to $/lb/day, though some are reported in terms of $/ton/year; ERCs are purchased once and apply for the life of the project.

cycle plant at 0.0026 lb/MMBtu of natural gas; this value is used to calculation the avoided emissions from both the average avoided natural gas-fired plant and the natural gas-fired peaking unit.

For the assumed heat rate range of 7,907-7,967 Btu/kWh for the average avoided natural gas-fired plant, the resultant SO_2 emissions rate is approximately 0.021 lb/MWh. For the avoided peaking unit at the assumed heat rate range of 10,450-10,833 Btu/kWh, the resultant SO_2 emissions rate is 0.027-0.028 lb/MWh.

As was the case for NO_x emissions, the value of the avoided SO_2 emissions is based on observed prices for one-time ERCs bought and sold in California, which are priced in $/lb/day. The range of prices for SO_2 ERCs used is this analysis is $40,275-$244,751/lb/day. Combining the calculated range of avoided SO_2 emissions and the applicable range of prices for each of the avoided generating technologies yields a range of Value of Avoided SO_2 Emissions of 0.012-0.076 cents/kWh for the avoided peaking generator and 0.009-0.056 cents/kWh for the avoided average California natural gas-fired generator.

5. Value of Avoided VOC Emissions

The VOC emissions rate is estimated to be 0.012 lb/MMBtu for the both the avoided natural gas-fired peaking generator and for the average California avoided natural gas-fired plant.[71] Applying the applicable heat rate range to each of the avoided generators yields a range of VOC emissions of 0.125-0.130 lb/MWh for the avoided peaking generator and 0.095-0.096 lb/MWh for the average natural gas-fired plant.

The Value of Avoided VOC Emissions uses observed California VOC ERC prices of $6,633-$279,726/lb/day. The range of Value of Avoided VOC Emissions is 0.009-0.399 cents/kWh for the avoided peaking generator and 0.007-0.293 cents/kWh for the avoided average California natural gas-fired generator.

6. Value of Avoided PM10 Emissions

The methodology and data sources for calculating avoided emissions of particulate matter less than 10 microns in diameter (“PM10”) are the same as those used for valuing avoided NO_x emissions. For ease of analysis, only direct PM10 emissions are included in the analysis, likely resulting in an underestimated Value of PM10 Emissions due to lack of consideration of secondarily-formed PM10 emissions. The PM10 emissions rate for the average avoided natural gas-fired plant of 0.062-0.063 lb/MWh is calculated using the parameters in the updated E3 Electric Avoided Costs workbook and the heat rate range of 7,907-7,967 Btu/kWh. The PM10 emissions rate for the avoided natural gas-fired peaking generator is calculated in a similar manner, using the heat rate range of 10,405-10,833 Btu.kWh.

---

71 Abt Associates, October 2000, Exhibit C-2, p. C-5.

The Value of Avoided PM10 Emissions uses observed California PM10 ERC prices of $120,000-$410,959/lb/day. The resultant range of Value of Avoided PM10 Emissions is 0.102-0.359 cents/kWh for the avoided peaking generator and 0.082-0.283 cents/kWh for the avoided average California natural gas-fired generator.

7. Value of Avoided CO Emissions

The CO emissions rate is estimated to be 0.1095 lb/MMBtu for both of the avoided natural gas-fired generators.[72] Applying the applicable heat rate range to each avoided generator results in a range of CO emissions of 1.144-1.186 lb/MWh for the peaking generator and 0.866-0.872 lb/MWh for the average California avoided natural gas-fired plant.

The Value of Avoided CO Emissions is based on observed California CO ERC prices of $4,214-$8,337/lb/day of CO emissions. Multiplying the endpoints of these prices times the end-points of the avoided CO emissions results in a Value of Avoided CO Emissions of 0.053-0.108 cents/kWh for the avoided peaking generator and 0.04-0.08 cents/kWh for the avoided average California natural gas-fired generator.

8. Value of Health Benefits

By far the largest contributor to the Value of Health Benefits attributable to avoided emissions is any reduction in particulate matter, particularly any reduction in particulate matter less than 2.5 microns in diameter ("PM2.5"). PM2.5 emissions are a subset of PM10 emissions, but PM2.5 emissions are more damaging to health because they lodge deeper in the lungs, and cannot readily be coughed out.

PM2.5 emissions are estimated to comprise 98% of total PM10 emissions in California's electricity generation sector, based on the statewide estimated annual average emissions published by the California Air Resources Board for calendar year 2000 for electric generation and cogeneration.[73] Calendar year 2000 emissions of direct PM2.5 and PM10 provided the basis upon which to calculate the tons per day of each that would be required to achieve the 33% reduction underlying California-specific calculations of the health-related economic value of reducing PM2.5 and PM10 emissions.[74] [75] Combining results from these sources, the health-related economic value

---

72 *Ibid.*

73 California Air Resources Board, 2001, online Almanac Emission Projection Data.

74 *See* Hall, *et al.*, 2006; California Environmental Protection Agency and California Air Resources Board, May 3, 2002, May 31, 2003, and March 21, 2006. (Note that Appendix A to the March 21, 2006 report was included in the September 2008 Public Health Analysis Supplement of the California Air Resources Board Climate Change Draft Scoping Plan.)

75 *See* Hall, *et al.*, 2008, for a more-recent analysis of the benefits of ozone and PM2.5 reductions in California's South Coast Air Basin and San Joaquin Valley. Derived benefits per avoided incident are similar to those in the Abt Associates study except in the instance of avoided Mortality, where the derived value of avoided Mortality is $6.6 million per incident in Hall, *et al.*, (pp. 78-83) compared to the Abt

of the 33% reduction in PM2.5 and PM10 emissions was divided by the corresponding physical tons to calculate the Value of Health Benefits for PM2.5, which ranges from 2.327-2.395 cents/kWh for the avoided peaking generator and 1.874-1.885 cents/kWh for the avoided average California natural gas-fired generator. The additional value for avoided >PM2.5-PM10 emissions is 0.010-0.011 cents/kWh for the avoided peaking generator and 0.008 cents/kWh for the avoided average California natural gas-fired generator.

The health benefits of reduced NO_x and SO_2 power plant emissions on a cents/kWh basis are derived using the results of an extensive October 2000 study by Abt Associates. The Abt Associates study provides both nationwide and state-specific estimates of health benefits in terms of avoided incidences of mortality, hospitalizations, and various categories of illness. These estimates were used to calculate the value of California-specific benefits based on the proportion of California-specific avoided health-related incidences to nationwide totals.[76]

Total California health benefits as derived from the Abt Associates study were divided by 75% of California's total 1997 NO_x and SO_2 power plant reductions to arrive at a value of $1.02/lb (1999$) of reduced emissions.[77] The $1.02/lb (1999$) of reduced emissions was inflated to 2008$ and then converted to cents/kWh using estimated NO_x and SO_2 emissions rates from the Updated E3 Electric Avoided Costs Workbook for the heat rate range of 7,907-7,967 Btu/kWh for the average California natural gas-fired plant and for the heat rate range of 10,450-10,833 Btu/kWh for the avoided natural gas-fired peaking unit. The Value of Health Benefits for avoided NO_x and SO_2 emissions ranges from 0.026-0.028 cents/kWh for the avoided peaking generator and 0.016 cents/kWh for the avoided average California natural gas-fired generator.

The total Value of Health Benefits, including the values for avoided PM2.5, PM10, NO_x and SO_2, is 2.363-2.434 cents/kWh for the avoided peaking generator and 1.898-1.909 cents/kWh for the avoided average California natural gas-fired generator.

Associates derived value of $7.3 million (in 2008$). The Abt Associates derived value used in this study is approximately mid-way between the recent Hall, *et al.*, analysis and the $8.7 million (in 2008$) value of avoided Mortality in the California Environmental Protection Agency and California Air Resources Board March 21, 2006 report (p. A-67).

[76] Abt and Associates, October 2000, Exhibits 6-2 and 6-7.

[77] A 75% reduction in NO_x and SO_2 was the underlying assumption in the health benefits calculated in the Abt Associates study. A 75% reduction in total 1997 California electricity utility emissions as reported by the U.S. Department of Energy was used to calculate the $/lb value, based on the total California-specific health benefits derived from the Abt Associates study. (*See* U.S. Department of Energy, Electric Power Annual, Table 5.1.)

H. OTHER VALUES NOT YET QUANTIFIED

In addition to the benefits of LSSP that have been quantified above, there are other benefits that have not yet been fully quantified.

1. Value of Reduced Reliance on Natural Gas Imports

Although the market value of avoided natural gas use due to solar-generated electricity from LSSP systems has been quantified in the Value of Avoided Generation Fuel Cost, the intrinsic value to Californians of reduced natural gas import reliance has not been quantified in this analysis.

2. Value of Increased National Energy Security

The national energy security benefits of using California's indigenous and bountiful solar resource are intuitive, but difficult to quantify. Any national energy security benefits attributed to increased use of California's indigenous solar resources must be net of any identifiable security risks related to increased solar-generated electricity.

3. Value of Waste Heat Use and Shading from LSSP Systems

LSSP technologies generate a significant amount of heat. Waste heat from the steam turbines of LSSP plants could be used for the desalination of sea water, which would be particularly useful in arid regions where fresh water is scarce. Thus land that is now unproductive from a human perspective could become a horticultural zone providing food crops and other produce if sufficient water were available. In addition, the mirrors in the solar field could provide strategic areas of shade.[78]

4. Environmental Issues

The environmental benefits of renewable energy, on the whole, are far greater than those of fossil fuel energy resources. However, no energy generating resource is entirely environmentally benign, and LSSP plants are no exception. Developing LSSP projects requires flat land surface, and consequently some physical flattening, or "scraping", of land is required. This scraping both disturbs the original surface of the land and emits a certain amount of particulate matter into the atmosphere. The construction of solar thermal power plants also generates some pollution from trucks at the project site, construction activities, and transport of plant components to the project site. LSSP plants are located in areas where the solar resource is the most valuable, which is typically in arid regions. While many solar projects that are currently in the planning stages for California will employ dry cooling technology, there is still some water required for regular mirror washing and dust control.

---

[78] Renewable Energy Focus, January/February 2008, p. 43.

Some LSSP projects in California may be located in areas that are also occupied by sensitive species, namely the Mohave ground squirrel and the desert tortoise, and will require adequate planning and protection measures. This analysis is not intended to ignore these impacts.

I. CONCLUSIONS

LSSP systems in California can provide significant value to Californians through the displacement of electricity generated largely with imported natural gas with electricity generated using California's bountiful and indigenous solar resource. In addition to natural gas savings, electricity generated using LSSP systems avoids the air emissions associated with natural gas combustion and contributes to associated health benefits. This analysis has described the methodology used to calculate the benefits of LSSP systems with TES in California. Peak-demand period LSSP generation displaces natural gas-fired peaking generators, and provides a value of 13.9-32.7 cents/kWh. Shoulder-demand period LSSP generation displaces the average California natural gas-fired generator, providing a value of 9.4-22.9 cents/kWh.

* * * * * * *

ACKNOWLEDGEMENTS

This analysis was commissioned by the Energy Foundation and coordinated through the Center for Energy Efficiency and Renewable Energy Technologies and the Large Scale Solar Association. The analysis was performed by Lori Smith Schell, Ph.D., of Empowered Energy. The following independent reviewers provided additional clarity and detail to the final report:

- Cliff Chen, Union of Concerned Scientists
- Mark Mehos, National Renewable Energy Laboratory
- Noah Long, Natural Resources Defense Council
- Shankar Prasad, Coalition for Clean Air
- Sheryl Carter, Natural Resources Defense Council

The Energy Foundation

Toward a sustainable energy future

SELECTED REFERENCES

Abt Associates, Inc., October 2000, "The Particulate-Related Health Benefits of Reducing Power Plant Emissions." http://www.abtassociates.com/reports/particulate-related.pdf

American Solar Energy Society, January 2007, "Tackling Climate Change in the U.S. – Potential Carbon Emissions Reductions from Energy Efficiency and Renewable Energy by 2030." http://www.ases.org/images/stories/file/ASES/climate_change.pdf

Aringhoff, Rainer, March 5, 2008, "A Market Outlook for CSP in the US Southwest (with a focus on CA): Assessment from a Developer's Point of View: Bright Future with some dark spots at present," presentation to IEA Solar PACES, 14th Biennial Concentrating Solar Power Symposium, Las Vegas, Nevada.

http://solarpaces2008.sandia.gov/SolarPACES%20PLENARIES/2%20WEDNESDAY%20INDUSTRY%20DAY%20SESSIONS/3%20MARKET%20OUTLOOK/05%20Aringhoff%20Market%20Evolution%20.pdf

Ausra, Inc., 2007, "An Introduction to Solar Thermal Electric Power." http://ausra.com/pdfs/SolarThermal101_final.pdf

Bolinger, Mark and Ryan Wiser, January 7, 2008, "Memorandum: Comparison of AEO 2008 Natural Gas Price Forecast to NYMEX Futures Prices." http://eetd.lbl.gov/ea/ems/reports/53587_memo.pdf

Bolinger, Mark, Ryan Wiser, and William Golove, January 2004, "Accounting for Fuel Price Risk When Comparing Renewable to Gas-Fired Generation: The Role of Forward Natural Gas Prices," Ernest Orlando Lawrence Berkeley National Laboratory, Environmental Technologies Division, LBNL-54751. http://eetd.lbl.gov/EA/EMP/reports/54751.pdf

California Air Resources Board, October 2008, "Climate Change Proposed Scoping Plan Appendices, Volume I: Supporting Documents and Measure Detail." http://www.arb.ca.gov/cc/scopingplan/document/appendix1.pdf

California Air Resources Board, September 2008, "Climate Change Draft Scoping Plan, Public Health Analysis Supplement, Attachment D – Method Used to Quantify Health Benefits of Draft Scoping Plan Co-Pollutant Emission Reductions: Appendix A – Quantification of the Health Impacts and Economic Valuation of Air Pollution from Ports and Goods Movement in California (March 21, 2006)." http://www.arb.ca.gov/cc/scopingplan/document/ph_health_methodology_d.pdf

California Air Resources Board, 2001, "2000 Estimated Annual Average Emissions, Statewide."

http://www.arb.ca.gov/app/emsinv/emssumcat_query.php?F_YR=2000&F_DIV=-4&F_SEASON=A&SP=2006&F_AREA=CA

California Department of Finance, January 2009, "California Statistical Abstract, 2008 Edition." http://www.dof.ca.gov/HTML/FS_DATA/STAT-ABS/Toc_xls.htm

California Energy Commission, December 2007, "Comparative Costs of California Central Station Electricity Generation Technologies," Final Staff Report, CEC-200-2007-011-SF. http://www.energy.ca.gov/2007publications/CEC-200-2007-011/CEC-200-2007-011-SF.PDF

California Energy Commission, August 2007, "Comparative Costs of California Central Station Electricity Generation Technologies: Appendix B – Renewable Energy Cost of Generation Inputs," Consultant Report prepared by Navigant Consulting, CEC-200-2007-011 APB. http://www.energy.ca.gov/2007publications/CEC-200-2007-011/CEC-200-2007-011-SF-APB.PDF

California Energy Commission, 2007, "2007 Integrated Energy Policy Report," CEC-100-2007-008-CMF. http://www.energy.ca.gov/2007publications/CEC-100-2007-008/CEC-100-2007-008-CMF.PDF

California Energy Commission, April 2006, "Cost and Value of Water Use at Combined-Cycle Power Plants," CEC-500-2006-034. http://www.energy.ca.gov/2006publications/CEC-500-2006-034/CEC-500-2006-034.PDF

California Energy Commission, November 2005, "Solar Thermal Parabolic Trough Electric Power Plants for Electric Utilities in California," PIER Final Project Report, Prepared by Solargenix Energy. http://www.energy.ca.gov/2005publications/CEC-500-2005-175/CEC-500-2005-175.PDF

California Environmental Protection Agency, May 2005, "California Hydrogen Blueprint Plan, Volume 2." http://www.hydrogenhighway.ca.gov/plan/reports/volume2_050505.pdf

California Environmental Protection Agency and California Air Resources Board, March 21, 2006, "Proposed Emission Reduction Plan for Ports and Goods Movement in California." http://www.arb.ca.gov/planning/gmerp/march21plan/march22_plan.pdf

California Environmental Protection Agency and California Air Resources Board, June 2005, "Characterization of Ambient PM10 and PM2.5 in California – Technical Report." http://www.arb.ca.gov/pm/pmmeasures/pmch05/stateover05.pdf

California Environmental Protection Agency and California Air Resources Board, May 31, 2003, "The Economic Value of Respiratory and Cardiovascular Hospitalizations,"

Final Research Report, Contract Number 99-329.
http://www.arb.ca.gov/research/apr/past/99-329.pdf

California Environmental Protection Agency and California Air Resources Board, May 3, 2002, "Staff Report: Public Hearing to Consider Amendments to the Ambient Air Quality Standards for Particulate Matter and Sulfates."
http://www.arb.ca.gov/research/aaqs/std-rs/pm-final/pm-final.htm

California Public Utilities Commission, January 16, 2009, "Proposed Decision of ALJ Brown, Application 07-012-029, Application of Southern California Edison Company (U338-E) for Recovery of Peaker Costs." http://docs.cpuc.ca.gov/efile/PD/96252.pdf

California Public Utilities Commission, December 18, 2008, "Resolution E-4214," 2008 Market Price Referent. http://docs.cpuc.ca.gov/Published/Agenda_resolution/94756.htm

California Public Utilities Commission, February 10, 2005, "Revised 2004 Market Price Referent Staff Report – MPR Methodology to Determine the Long-Term Market Price of Electricity for Use in California's 2004 Renewables Portfolio Standard (RPS) Power Solicitations." http://docs.cpuc.ca.gov/word_pdf/RULINGS/43825.pdf

CALPIRG Charitable Trust, June 2002, "Renewables Work – Job Growth from Renewable Energy Development in California."
http://www.environmentcalifornia.org/uploads/Gg/7m/Gg7mP2qpr4ZGj0deZnKIzQ/Renewables_Work.pdf

CantorCO2e Environmental Brokerage, various emissions, various California markets.
http://CantorCO2e.com

Center for Energy Efficiency and Renewable Technologies, February 7, 2009, "Harvesting California's Renewable Energy Resources: A Green Jobs Business Plan (Revised)."
http://www.ceert.org/reports_pdf/Harvesting_California_Renewable_Energy_Resources_II_Final.pdf

Centers of Excellence, June 2008, "Emerging Industry & Occupations Report: Solar Study/2008," California Community Colleges Economic & Workforce Development.
http://www.coeccc.net/solar/documents/Emerging_solar_08.pdf

Chicago Climate Exchange, Various Dates, "CCX Market Report," Historic Electronic Pricing Files. http://www.chicagoclimateexchange.com

CPV Today, November 24, 2008, "Interview with Hansjörg Lerchenmüller, CEO. Concentrix Solar GmbH." http://social.cpvtoday.com/content/interview-hansjörg-lerchenmüller-ceo-concentrix-solar-gmbh

Duke, Richard, Robert Williams and Adam Payne, 2004, "Accelerating Residential PV Expansion: Demand Analysis for Competitive Electricity Markets," *Energy Policy*. http://www.sciencedirect.com/science/article/B6V2W-4C6TH1K-1/2/cbca1c88be2b5d8b92a7034ab0f93939

Earth Policy Institute, July 22, 2008, "Solar Thermal Power Coming to a Boil." http://www.earth-policy.org/Updates/2008/Update73_printable.htm

ECOSTAR, February 15, 2005, "European Concentrated Solar Thermal Road-Mapping, Deliverable No. 7: Roadmap Document," SES6-CT-2003-502578. http://www.vgb.org/data.o/vgborg_/Forschung/roadmap252.pdf

Electric Power Research Institute, March 2007, "Renewable Energy Technical Assessment Guide – TAG-RE: 2006," Final Report, 1012722. http://my.epri.com/portal/server.pt/gateway/PTARGS_0_2_1630_277_848_43/http%3B/myepri10%3B80/EPRIDocumentAccess/popup.aspx/000000000001012722

Electric Power Research Institute, November 2001, "California Renewable Tecnology Market and Benefits Assessment," Final Report, 1001193. http://my.epri.com/portal/server.pt/gateway/PTARGS_0_2_1630_277_848_43/http%3B/myepri10%3B80/EPRIDocumentAccess/popup.aspx/000000000001001193

Energy and Environmental Economics, Inc., May 13, 2008, "Greenhouse Gas Calculator, Version 2.b." http://www.ethree.com/CPUC_GHG_Model.html

Energy and Environmental Economics, Inc., 2008, "2008 Market Price Reference Model," Final Public Version. http://www.ethree.com/downloads/MPR/2008%20MPR%20Model%20E4214%20Final%20Public.xls

Energy and Environmental Economics, Inc., March 20, 2006, "Avoided Cost Calculation Spreadsheets, Updated Electric and Gas Avoided Costs – 2006 Update (5/23/06 Draft Decision): Electric Avoided Costs." ("Updated E3 Electric Avoided Costs Workbook") http://www.ethree.com/cpuc_avoidedcosts.html

Energy and Environmental Economics, Inc., and Rocky Mountain Institute, October 25, 2004, "Methodology and Forecast of Long Term Avoided Costs for the Evaluation of California Energy Efficiency Programs," report prepared for the California Public Utilities Commission. ("E3 Avoided Cost Study") http://www.ethree.com/CPUC/E3_Avoided_Costs_Final.pdf

Energy and Environmental Economics, Inc., March 20, 2006, "Avoided Cost Calculation Spreadsheets, Updated Electric and Gas Avoided Costs – 2006 Update (5/23/06 Draft Decision): Electric Avoided Costs." http://www.ethree.com/cpuc_avoidedcosts.html

Environment California Research & Policy Center, January 2009, "Clean Energy, Bright Future: Rebuilding America through Green Infrastructure." http://www.environmentcalifornia.org/uploads/h7/8_/h78_c2ACC166g69RLma--Q/CA---Clean-Energy-Bright-Future.pdf

European Commission, 2007, "Concentrating Solar Power – From Research to Implementation," Directorate-General for Energy and Transport and Directorate-General for Research. http://www.solarpaces.org/Library/CSP_Documents/2007_concertrating_solar_power_en.pdf

Hall, Jane V., Victor Brajer, and Frederick W. Lurmann, November 2008, "The Benefits of Meeting Federal Clean Air Standards in the South Coast and San Joaquin Valley Air Basins." http://business.fullerton.edu/centers/iees/reports/Benefits%20of%20Meeting%20Clean%20Air%20Standards.pdf

Hall, Jane V., Victor Brajer, and Frederick W. Lurmann, March 2006, "The Health and Related Economic Benefits of Attaining Healthful Air in the San Joaquin Valley," Institute for Economic and Environmental Studies, California State University-Fullerton. http://business.fullerton.edu/Centers/iees/reports/SJVFinalReport.pdf

Herig, Christy, September 2001, "Using Photovoltaics to Preserve California's Electricity Capacity Reserves," National Renewable Energy Laboratory, NREL/BR-520-31179. http://www.nrel.gov/docs/fy01osti/31179.pdf

Itron, Inc., September 2008, "CPUC Self-Generation Incentive Program Seventh-Year Impact Evaluation: Final Report," Delivered to PG&E and The Self-Generation Incentive Program Working Group. http://www.cpuc.ca.gov/NR/rdonlyres/13D12230-5974-44C7-A90B-4F7C53CAA543/0/SGIP_7thYearImpactEvaluationFinalReport.pdf

Mills, Andrew, Ryan Wiser, and Kevin Porter, February 2009, "The Cost of Transmission for Wind Energy: A Review of Transmission Planning Studies," Ernest Orlando Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division, LBNL-1471E. http://eetd.lbl.gov/ea/ems/reports/lbnl-1471e.pdf

National Renewable Energy Laboratory, December 5, 2008, "Solar Advisor Model – DRAFT CSP Reference Manual," SAM Version 2.5. https://www.nrel.gov/analysis/sam/pdfs/sam_csp_reference_manual_2.5.pdf

National Renewable Energy Laboratory, April 2006, "Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California," Subcontractor Report, Prepared by Black & Veatch, NREL/SR-550-39291. http://www.nrel.gov/csp/pdfs/39291.pdf

National Renewable Energy Laboratory, October 2003, "Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts," Subcontractor Report, Prepared by Sargent & Lundy LLC Consulting Group, NREL/SR-550-34440. http://www.nrel.gov/docs/fy04osti/34440.pdf

National Renewable Energy Laboratory, July 2002, "Fuel from the Sky: Solar Power's Potential for Western Energy Supply," NREL/SR-550-32160. http://www.nrel.gov/csp/pdfs/32160.pdf

National Renewable Energy Laboratory, undated, Job and Economic Development Impact Models, "JEDI Solar Model, CSP Trough Model rel. CSP1.08.02a." http://www.nrel.gov/analysis/jedi

Navigant Consulting, September 15, 2008, "Economic Impacts of Extending Federal Solar Tax Credits: Final Report," Prepared for the Solar Energy Research and Education Foundation (SEREF). http://www.seia.org/galleries/pdf/Navigant%20Consulting%20Report%209.15.08.pdf

Perez, R., R. Margolis, M. Kmiecik, M. Schwab, and M. Perez, June 2006, "Update: Effective Load-Carrying Capability of Photovoltaics in the United States," Preprint Conference Paper, National Renewable Energy Laboratory, NREL/CP-620-40068. http://www.nrel.gov/pv/pdfs/40068.pdf

Prometheus Institute and Greentech Media, 2008, "Concentrating Solar Power – Technology, Cost, and Markets, 2008 Industry Report," Executive Summary and Excerpts from Final Report, as indicated below: http://www.greentechmedia.com/assets/pdfs/executivesummaries/Concentrating-Solar-Power-Final-Executive-Summary.pdf

http://www.greentechmedia.com/assets/images/Concentrating-Solar-Power-Final-87.gif

Renewable Energy Focus, 2008, various issues, as indicated below:

January/February 2008: "CSP Concentrates the Mind," pp. 42-47. http://www.trec-uk.org.uk/articles/REF/ref_0901_p42_47.pdf

March/April 2008: "Parabolic Troughs: CSP's Quiet Achiever," pp. 46-50. http://www.trec-uk.org.uk/articles/REF/ref_0902_pg46_51.pdf

May/June 2008: "Hot Stuff: CSP and the Power Tower," pp. 51-54. http://www.trec-uk.org.uk/articles/REF/ref_0903_pg51_55.pdf

July/August 2008: "CSP: Dish Projects Inch Forward," pp. 52-54. http://www.trec-uk.org.uk/articles/REF/ref0904_pg52_55.pdf

September/October 2008: "CSP: Bright Future for Linear Fresnel Technology?"

pp. 48-51. http://www.trec-uk.org.uk/articles/REF/ref0905_p48_51.pdf

November/December 2008: "Innovation in CSP," pp. 44-49. http://www.skyfuel.com/downloads/articles/InnovationInCSP(RE_Focus)Dec08.pdf

Renewable Energy Policy Project, November 2001, "The Work That Goes Into Renewable Energy," Research Report, No. 13. http://www.repp.org/articles/static/1/binaries/LABOR_FINAL_REV.pdf

Renewable Energy Transmission Initiative, January 2009, "Renewable Energy Transmission Initiative, Phase 1B, Final Report," RETI-1000-2008-003-F. http://www.energy.ca.gov/2008publications/RETI-1000-2008-003/RETI-1000-2008-003-F.PDF

Spath, Pamela L. and Margaret K. Mann, February 2001, "Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming." National Renewable Energy Laboratory Technical Report, NREL/TP-570-27637. http://www.nrel.gov/docs/fy01osti/27637.pdf

Ummel, Kevin, and David Wheeler, December 2008, "Desert Power: The Economics of Solar Thermal Electricity for Europe, North Africa, and the Middle East," Working Paper 156, Center for Global Development, Washington, D.C. http://www.trec-uk.org.uk/reports/CGD_desert_power_2008-12-12.pdf

U.S. Bureau of Labor Statistics, "Current Employment Statistics (CES) – National, Table B-2. Average Hours and Earnings of Production and Nonsupervisory Workers on Private Nonfarm Payrolls by Major Industry Sector, 1964 to date." ftp://ftp.bls.gov/pub/suppl/empsit.ceseeb2.txt

U.S. Department of Energy, September 19, 2008, "DOE Funds 15 New Projects to Develop Solar Power Storage and Heat Transfer Projects For Up to $67.6 Million," Press Release. http://www.energy.gov/print/6562.htm

U.S. Department of Energy, June 2008, "Assumptions to the Annual Energy Outlook 2008, with Assumptions for 2030," Energy Information Administration, DOE/EIA-0554(2008). http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/0554(2008).pdf

U.S. Department of Energy, April 15, 2008, "Solar Energy Technologies Program, Multi Year Program Plan, 2008-2012," Energy Efficiency and Renewable Energy, Solar Energy Technologies Program. http://www1.eere.energy.gov/solar/pdfs/solar_program_mypp_2008-2012.pdf

U.S. Department of Energy, February 7, 2008, "A Plan for the Integrated Research, Development, and Market Transformation of Solar Energy Technologies - DRAFT," Energy Efficiency and Renewable Energy, Solar Energy Technologies Program, SETP-

2006-0010.
http://www1.eere.energy.gov/solar/solar_america/pdfs/sai_draft_plan_Feb5_07.pdf

U.S. Department of Energy, February 2007, "Report to Congress on Assessment of Potential Impact of Concentrating Solar Power for Electricity Generation (EPACT 2005 – Section 934(c))," Energy Efficiency and Renewable Energy, Solar Energy Technologies Program, DOE/GO-12007-2400.
http://www.nrel.gov/csp/troughnet/pdfs/41233.pdf

U.S. Department of Energy, Energy Information Administration, January 21, 2009, "Electric Power Annual with Data for 2007," Table 5.1. Emissions from Energy Consumption at Conventional Power Plants and Combined-Heat-and-Power Plants, 1996 through 2007. Microsoft Excel file emission_state.xls at:
http://www.eia.doe.gov/cneaf/electricity/epa/epat5p1.html.

U.S. Department of Energy and U.S. Department of the Interior, February 2003, "Assessing the Potential for Renewable Energy on Public Lands," DOE/GO-102003-1704. http://www.nrel.gov/csp/pdfs/33530.pdf

Western Governors' Association, January 2006, "Clean and Diversified Energy Initiative," Report of the WGA Solar Task Force.
http://www.westgov.org/wga/initiatives/cdeac/Solar-full.pdf

Wiser, Ryan, Mark Bolinger, and Matt St. Clair, January 2005, "Easing the Natural Gas Crisis: Reducing Natural Gas Prices through Increased Deployment of Renewable Energy and Energy Efficiency," Ernest Orlando Lawrence Berkeley National Laboratory, Environmental Technologies Division, LBNL-56756.
http://eetd.lbl.gov/EA/EMP/reports/56756.pdf

Attachment A

ASSUMPTIONS AND RESULTS FOR AVOIDED EMISSIONS AND RELATED VALUE OF HEALTH BENEFITS

	Heat Rate Range (Btu/kWh)	Emissions Rate (CO_2 in tons/MWh; all others in lb/MWh)					
		NO_x	SO_2	PM10	CO	VOC	CO_2
LSSP Technologies	n/a	-	-	-	-	-	-
Average CA Natural Gas-Fired Generator	7,967	0.103	0.021	0.063	0.872	0.096	0.466
	7,907	0.101	0.021	0.062	0.866	0.095	0.463
Natural Gas-Fired Peaking Generator	10,833	0.185	0.028	0.080	1.186	0.130	0.634
	10,405	0.174	0.027	0.077	1.144	0.125	0.611
Emissions Prices		NO_x	SO_2	PM10	CO	VOC	CO_2
	In-State:	($/lb/day)	($/lb/day)	($/lb/day)	($/lb/day)	($/lb/day)	($/ton)
	Maximum	$374,384	$244,751	$410,959	$8,337	$279,726	$27.27
	Minimum	$ 47,000	$ 40,275	$120,000	$4,214	$ 6,633	$ 8.00
LSSP: Value of Avoided Emissions (cents/kWh)							
		NO_x	SO_2	PM10	CO	VOC	CO_2
vs. Average CA Natural Gas-Fired Generator	Maximum	0.423	0.056	0.283	0.080	0.293	1.271
	Minimum	0.052	0.009	0.082	0.040	0.007	0.370
vs. Natural Gas-Fired Peaking Generator	Maximum	0.758	0.076	0.359	0.108	0.399	1.728
	Minimum	0.089	0.012	0.102	0.053	0.009	0.489

LSSP: Value of Health Benefits Associated with Avoided Emissions (cents/kWh)					
		NO_x & SO_2	PM10	PM2.5*	* *PM2.5 emissions make up 98% of the PM10 emissions category by weight, per California Air Resources Board 2000 Emissions Inventory.*
vs. Average CA Natural Gas-Fired Generator	Maximum	0.016	0.008	1.885	
	Minimum	0.016	0.008	1.874	
vs. Natural Gas-Fired Peaking Generator	Maximum	0.028	0.011	2.395	
	Minimum	0.026	0.010	2.327	

APPENDIX A:
LARGE-SCALE SOLAR TECHNOLOGY OVERVIEW

This technology overview of large-scale solar power ("LSSP") technologies is designed to provide the reader with basic information about a number of utility-scale solar electric generating technologies. A number of these technologies concentrate the sun's energy on a thermal conductor (*i.e.*, water, molten salt or oil for most thermal electric systems; helium or hydrogen for dish-engine systems) and then use the resultant heat to move an engine or turbine. These technologies concentrate the sun's energy using concave or flat mirrors that are arranged in a line or around a point. Photovoltaic technologies create electricity directly, and may or may not concentrate the sun's energy using mirrors or reflectors. Concentrating thermal systems tend to have higher day-to-day operating and maintenance costs than PV systems because of more moving parts and the heat generated, though PV systems incur periodic inverter replacement costs (every 10-15 years). Concentrating thermal systems also have the potential to store the heat generated or to use the heat in systems hybridized with natural gas to make dispatchable power. The directly generated electricity from PV systems makes storage more difficult, and limits the dispatchability of PV-generated electricity.[79]

Concentrating thermal electric and photovoltaic systems rely on direct normal irradiation ("DNI"), which is that portion of sunlight that comes directly from the sun and falls perpendicular to the solar collector. This is in contrast to diffusion insolation, which is that portion of sunlight that has been scattered by the atmosphere or is reflected off the ground or other surfaces.[80] Total insolation is the amount of solar energy striking a flat surface over time. Non-concentrating PV can use total insolation, *i.e.*, both the DNI and diffuse sunlight, to directly generate electricity. For this reason, concentrating solar collectors are much more sensitive to solar resource characteristics than are flat-plate PV collectors.[81] Depending on latitude, DNI can range from 60-80% of total insolation. Some of the loss of available sunlight to concentrating thermal technologies is offset by the higher efficiency of the solar-to-electricity conversion efficiency of concentrating thermal technologies compared to non-concentrating PV technology. Concentrating thermal technologies are best suited for middle-latitude climates with high sun and minimal cloud cover. [82]

The quality of the solar resource is location-specific. A common measure of total insolation is average energy per unit area per day, expressed in terms of kilowatt-hour per square meter per day ("kWh/m^2/day"). The range of average insolation in the United

79 Prometheus Institute and Greentech Media, 2008, p. 3.

80 http://www.energymanagertraining.com/power_plants/sources_of%20_energy.htm

81 U.S. Department of Energy and U.S. Department of the Interior, February 2003, p. B2.

82 Prometheus Institute and Greentech Media, 2008, p. 4.

States on a flat, horizontal surface is roughly 3.0-5.8 kWh/m^2/day.[83] Concentrating thermal systems are generally deemed to require a minimum average annual DNI of 6.0 kWh/m^2/day. The Southwest has the best solar resource in the United States, with average annual DNI for land having no greater than a 3% slope, as shown below in Figure A-1.

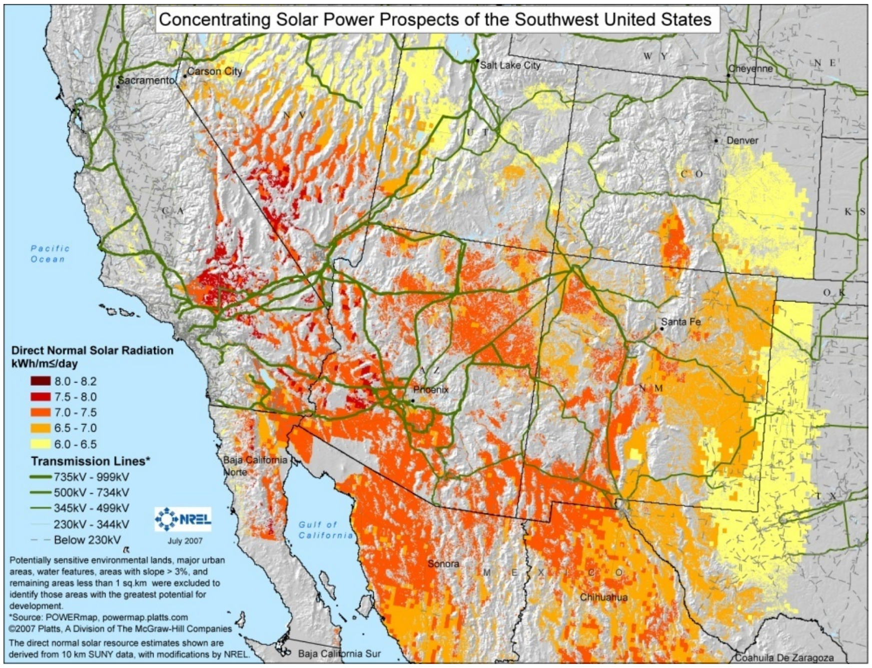

Figure A-1. Annual Average Direct Normal Insolation, Land with ≤3% Slope (Source: National Renewable Energy Laboratory)

The federal Solar America Initiative, launched in 2006, aims to boost research and development ("R&D") to reduce costs and expand production of solar technologies while also achieving market transformation through non-R&D activities that will reduce market and institutional barriers and promote deployment of solar energy technologies.[84]

Table A-1, located at the end of this technology overview, summarizes some of the operating and cost characteristics of the six types of solar electric generating technologies described herein. Although the cost per kWe for LSSP systems appears high relative to conventional central station generating plants, it must be remembered that this cost per kWe includes "virtually" the lifetime fuel costs of the LSSP system.[85]

[83] American Solar Energy Society, January 2007, p. 94.

[84] U.S. Department of Energy, February 7, 2008, p. 6 and p. 36.

[85] ECOSTAR, p. 39.

Parabolic Troughs[86] [87] [88] [89]

The key components of a parabolic trough power plant are mirrors, receiver tubes, and a steam turbine system. The solar field of a parabolic trough plant consists of long parallel rows of trough-like solar collectors, typically aligned in a north-south orientation to track the sun in one axis. A parabolic trough solar collector is designed to concentrate the sun's rays via parabolic curved solar reflectors onto a heat absorber element – a "receiver tube" – located in the optical focal line of the collector. The receiver consists of a specially coated absorber tube that is embedded in an evacuated glass envelope and designed to achieve the high temperatures necessary to ensure high steam power-cycle efficiency. The troughs track the sun from east to west so that the sun's radiation is continuously focused on the receiver tube.

The heat transfer fluid (typically synthetic oil)[90] flowing through the receiver tube is heated to 752ºF, and is then pumped to a central power block where it passes through a series of heat exchanges. The collected heat is used to raise steam, which is then used to generate electricity in a conventional steam Rankine cycle. Beyond the heat exchanger, parabolic trough plants are just conventional steam plants that can use thermal energy storage or be hybridized with fossil fuel to generate electricity when the sun does not shine. A molten salt thermal energy storage system can be integrated into a parabolic trough plant to enable power dispatch.

[86] U.S. Department of Energy, April 15, 2008, p. 114 and p. 117.

[87] European Commission, 2007, p. 9.

[88] http://www1.eere.energy.gov/solar/linear_concentrators.html

[89] http://www1.eere.energy.gov/solar/linear_concentrator_rnd.html

[90] Water is the heat transfer fluid in a Direct Steam Generation ("DSG") system. Newer parabolic trough systems are being designed to use molten salt as the heat transfer fluid.

Figure A-2. Parabolic Trough Solar Thermal Power Plant, Kramer Junction, California (Source: National Renewable Energy Laboratory)

The key technical challenges for parabolic trough technology relate to improving the efficiency and reducing the installed capital cost of the solar field, including the concentrator and solar receiver.[91]

Dish/Engine Systems[92]

Solar dish/engine systems comprise a solar concentrator, or dish, and the power conversion unit ("PCU"). The PCU, which includes the thermal receiver and the engine-generator, is air-cooled, so cooling water is not required. The concentrator consists of mirrors that form a parabolic dish; the mirrors focus the sun's energy onto the thermal receiver, which is located at the focal point of the parabolic dish. The dish/engine system is mounted on a structure with 2-axis tracking so that the concentrator points continuously at the sun.[93]

The receiver absorbs the energy of the solar radiation and is the interface between the dish and the engine-generator. The receiver contains an intermediate heat transfer medium (hydrogen or helium gas) that transfers heat to the engine and may also be the working gas for the engine. The heat is transferred to (typically) a Stirling engine, which is an engine that uses external heat sources to expand and contract a gas. The engine sits at the focal point of the parabolic dish, with temperatures of the heat transfer gas reaching 1452ºF. The Stirling engine uses the heated fluid to move pistons, which provides the

91 U.S. Department of Energy, April 15, 2008, p. 117.

92 http://www1.eere.energy.gov/solar/dish_engines.html

93 U.S. Department of Energy, February 5, 2007, p. 20.

energy either to rotate the engine's crankshaft or to cause a pressure pulse, depending on the technology. This, in turn, drives a generator to produce electricity.[94]

Other types of engines may also prove useful in a dish/engine system and it is also possible for concentrating photovoltaics to act as the receiver.[95] Stirling engines offer high efficiency, high power density (i.e., power output per unit of volume), tolerance of non-uniform flux distributions, and the potential for long-term, low-maintenance operation; Stirling engines have far fewer parts than an automotive and are cleaner because the heat source is external to the engine.[96]

Dish/engine systems are modular in design, with standard systems currently sized up to 25kW. This modularity allows for flexibility in sizing and placement, making dish/engine (and CPV) systems well-suited to central station generation. Dish/engine systems have not generally been used with solar energy storage in the form of heat, though development efforts are underway to demonstrate the feasibility of doing so.[97] Similarly, efforts are underway to hybridize large dish/engine systems with natural gas firing to increase the ability of such systems to provide dispatchable power.

Figure A-3. Dish-Stirling Solar Thermal Power Plant (Source: Sandia National Laboratories)

94 U.S. Department of Energy, April 15, 2008, p. 114 and pp. 117-118.

95 Renewable Energy Focus, January/February 2008, p. 44.

96 U.S. Department of Energy, April 15, 2008, p. 118.

97 U.S. Department of Energy, September 19, 2008, p. 2.

The key technical challenges for dish/engine systems are improving the solar collector (e.g., optics and controls) and increasing the reliability of the engine (e.g., valves, seals, and controls).[98]

Power Towers[99]

Power tower systems lack the modularity of dish/engine systems in that they have a single receiver placed on top of a tall, centrally located tower. Therefore, power towers favor larger-scale systems with maximum DNI. The power tower is surrounded by hundreds of tracking mirrors (heliostats) that follow the apparent motion of the sun in the sky and that re-direct and focus sunlight onto the receiver. The solar energy is absorbed by the heat transfer fluid flowing through the receiver, reaching temperatures of 1050ºF. Some power towers use water/steam as the heat-transfer fluid, though advanced designs use molten salt because of its superior heat-transfer and energy-storage capabilities. Energy is transferred from the heat transfer fluid is used to generate steam to drive a conventional Rankine steam-turbine power block.

Power towers can be coupled with a molten-salt thermal energy storage system to increase the ability to dispatch power.[100]

Figure A-4. 10 MW Solar Two Power Tower Plant, Daggett, California (Source: Sandia National Laboratories)

[98] U.S Department of Energy, February 2007, p. 8.

[99] http://www1.eere.energy.gov/solar/power_towers.html

[100] U.S. Department of Energy, April 15, 2008, p. 115.

The key elements of a power tower system are the heliostats – provided with a two-axis tracking system – the receiver, the steam generation system, and the storage system. The number of heliostats will vary according to the particular receiver's thermal cycle and the heliostat design.[101] Power towers offer good longer-term prospects because of their relatively high solar-to-electrical efficiency.

Compact Linear Fresnel Systems

The linear Fresnel system may be considered as innovation for the direct steam generating ("DSG") parabolic trough system, since it is also designed for DSG rather than for the utilization of a heat transfer fluid. However, instead of using trough-shaped mirrors that track the sun, the Fresnel reflector is made up of long flat mirrors at varying angles that focus the sunlight on one or more receiver tubes that are mounted above the mirrors. The flat mirrors track the sun throughout the day to that the sunlight is always concentrated on the heat-collecting receiver tube.[102] A small parabolic mirror called a second-stage receiver is sometimes added atop the receiver to further focus the sunlight that did not directly hit the receiver.[103] The receiver tubes do not operate under a vacuum and steam is generated directly in the solar field, eliminating the need for costly heat exchangers. Superheated steam is used to spin a turbine that drives a generator to produce electricity. [104]

The simple structure of the flat mirrors in linear Fresnel systems lends itself to mass production, and these structures are considerably lighter than the concentrating structures of parabolic troughs, dish/engines, and power towers.[105] Linear Fresnel systems have higher intrinsic optical losses compared to parabolic trough systems,[106] but manufacturers believe that the lower optical performance will be offset by lower investment costs in the collectors due to the more-standardized components.[107]

---

101 European Commission, 2007, p. 9.

102 Renewable Energy Focus, January/February 2008, p. 44.

103 http://www.spg-gmbh.com/index.asp?document_id=161

104 http://www1.eere.energy.gov/solar/linear_concentrators.html

105 Renewable Energy Focus, September/October 2008, p. 49.

106 ECOSTAR, 2005, p. 47.

107 ECOSTAR, 2005, p. 132.

Figure A-5. Compact Linear Fresnel Reflector Power Plant, Kimberlina, California (Source: Ausra, Inc.)

Non-Concentrating Photovoltaics[108]

Photovoltaics ("PV") convert sunlight directly into electricity. Photovoltaics are highly modular, with the smallest element being the PV cell. PV solar cells are made of semiconducting materials similar to those used in computer chips. The most commonly used PV material is crystalline silicone, though new thin film technologies are now available that essentially "print" a few micrometers thickness of the semiconducting material onto a flexible film or onto a glass substrate. When direct or diffuse sunlight is absorbed by the semiconducting materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce direct-current ("DC") electricity. This process of converting sunlight directly into electricity is called the "photovoltaic effect."

Multiple solar cells of crystalline silicone are combined into a module, modules are wired in series into strings, and strings are wired in parallel to form a solar array. Ongoing efforts are being made to reduce material costs by developing processes with higher silicon utilization (e.g., thinner cells). For thin film systems, the thin film solar cells are connected together in a similar fashion to form a solar array. Thin film solar cells have a much higher rate of light absorption than do crystalline cells, which allows for material thicknesses approximately 100 times thinner than that of crystalline cells. Thin film manufacturers are working to increase module efficiency, create a robust encapsulation material, and achieving large area uniformity and high throughput rates.

[108] U.S. Department of Energy, April 15, 2008. p. 111-113.

Figure A-6. 15 MW Large-Scale Photovoltaic Power Plant,
Nellis Air Force Base, Nevada
(Photo: Courtesy of Sunpower Corp.)

Although a number of applications use the DC electricity from PV modules, the fastest-growing markets for PV integrate the panels into systems with power-conditioning inverters that convert the DC electricity into alternating current ("AC"). These systems are then interconnected to the electric grid and are referred to as grid-tied systems.[109] Losses in the inverter, wiring, and other balance-of-system components reduce the DC electricity output by 10-20%. As a result, the overall AC rating of a PV system is typically around 80% of its DC rating.[110]

Figure A-7. 10 MW Large-Scale Thin Film Photovoltaic Power Plant,
El Dorado, Nevada
(Photo: Courtesy of First Solar)

109 U.S. Department of Energy, February 7, 2008, p. 18.

110 American Solar Energy Society, January 2007, p. 94.

Concentrating Photovoltaics[111] [112]

PV solar cells are the most expensive components of a PV system on a per-area basis, accounting for up to 75% of a flat-plate module. The primary reason for using concentrators is to be able to use less solar cell material in a PV system;[113] concentrating PV systems increase power output while reducing the size or number of solar cells needed. Concentrating PV incorporates high-efficiency (III-V) semiconductors (or traditional silicon) solar cells with trackers and reflective or refractive optics. The required concentrating optics are significantly more expensive than the simple covers needed for flat-plat PV systems and can at best transmit only 90-95% of the incident light.

CPV modules take advantage of the high performance offered by expensive multi-junction cells while maintaining low costs by focusing sunlight by 100-1000 times onto small solar cells. The optics and the cells must be well integrated. The increased efficiencies of the multi-junction cells increases power density, though the significant concentration of sunlight requires dissipating heat away from the cells for two reasons: (i) Solar cell efficiencies decrease as temperatures increase, and (ii) higher temperatures threaten the long-term stability of the solar cells. Modules must be sealed to protect the solar cells from moisture, and the process of concentrating the sunlight requires 2-axis tracking that must be precisely calibrated.

Because they generate electricity directly from sunlight, CPV systems do not lend themselves well to the storage of solar energy in the form of heat and are not well-suited to hybridization with natural gas firing.[114]

---

[111] U.S. Department of Energy, April 15, 2008. p. 114 and p. 121.

[112] http://www1.eere.energy.gov/solar/concentrator_systems.html

[113] The SolFocus 1100S CPV system is reported to use 1/1000th of the expensive solar cell material compared to traditional PV modules. http://social.cpvtoday.com/content/solfocus-announces-its-new-cpv-solution To put this in more familiar terms, if a football field was completely covered in 17% efficient silicon PV cells, it would produce about 500 kW of electricity. The same area of multi-junction II-V solar cells with a concentration ratio of 500 would increase that figure by a factor of 1000, to 500 MW. http://compoundsemiconductor.net/cws/article/magazine/27051

[114] Renewable Energy Focus, January/February 2008, p. 45.

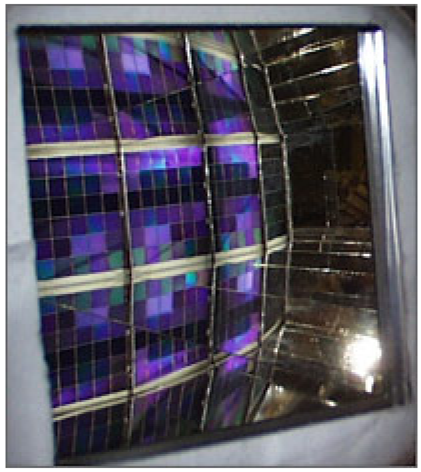

Figure A-8. Concentrating Photovoltaics: Dense Array of High-Efficiency Silicon Cells (Source: National Renewable Energy Laboratory)

The fundamental challenge of CPV is to lower cost, increase efficiency, and demonstrate reliability to overcome barriers to entry into the market on a large scale. Reliability factors specific to CPV include the high-flux, high-current, high-temperature operating environment encountered by the solar cells; weathering and other degradation of the optical elements; the bonding of the concentrating optics to the solar cell; and, the operation of the mechanical parts of the trackers.

The 2 MW combined PV/CPV Casaquemada power plant was connected to the Spanish electrical grid in 2008, mixing flat-plate PV with CPV. The advantage of such a combination system is a more even and constant power output curve. Flat-plate PV systems produce electricity during brief cloudy periods; CPV systems provide their peak power when it is very sunny, at which time flat-plate PV systems may experience some degradation due to high temperature. Combining the two types of PV systems draws on the strengths of both technologies. [115]

Benefits of Thermal Energy Storage

To provide high annual capacity factors with solar-only (i.e., no fossil fuel backup) power plants, a cost-effective thermal energy storage system must be integrated into the LSSP system. The collector field is then sized to collect more power that demanded by the steam generator system and the excess is “stored” in the thermal energy storage medium and accumulated in the hot storage tank. A power tower system with a molten nitrate salt TES can be built with annual capacity factors up to 70%.[116]

---

[115] CPV Today, November 24, 2008.

[116] ECOSTAR, 2005, p. 50.

The value of TES depends on the difference between daytime and nighttime electricity prices: the greater the diurnal price differential, the lower the value of TES. Ummel and Wheeler "purposely limited the deployment of CSP with storage to 25% of total program expansion to reflect the fact that storage systems at large scale are not yet in commercial operation…That said, the relative underdevelopment of CSP thermal storage systems does not limit the potential for profitable and effective deployment of CSP without storage. This is especially true when diurnal variation in electricity prices is significant, either as a result of time-of-use pricing structures or feed-in tariffs specific to daytime solar power."[117]

Addition of Hybridization with Natural Gas Firing

The thermal electric LSSP systems can be hybridized with a natural gas generator, to increase the operating flexibility of the LSSP system. The natural gas generator can be used to ensure that the LSSP system has adequate heat to generate electricity even when the sun is not shining and can also enable pre-heating of the LSSP system to maximize the hours of solar-only electricity generation.

[117] Ummel and Wheeler, December 2008, pp. 40-41.

Table A-1. Technology-Specific Assumptions for Large-Scale Solar Power Systems

	Parabolic Trough	Dish/Engine	Solar Power Tower	Compact Linear Fresnel	Concentrating PV	Large-Scale Photovoltaics
Solar Resource Used	DNI	DNI	DNI	DNI	DNI + diffuse	DNI + diffuse
Average Annual Capacity Factor[118]	25.9%; 41.04% (with TES)	24.29%	20%; 40.77% (with TES)	24%; 40% (with TES)	22.22%	23.58%
Heat Transfer Fluid (HTF)	Synthetic oil: 736ºF (391ºC); water steam: 986ºF (530ºC); molten salt: 1022ºF (550ºC+)	Hydrogen or helium gas	Water or molten salt	Oil or water	None; direct DC generation	None; direct DC generation
HTF Temperature[119]		1472ºF (800ºC)	1050ºF (565ºC)	545ºF (285ºC)[120]	n/a	n/a
Annual Solar-to-Electric Efficiency[121]	13.1% (2007); 15.5% (2011)	22% (2007); 24% (2011)	10% (Solar Two); 17%	12-14%[122]	20-26% (Si); 35-37% (III-V).	17% (Si)
Insolation Required[123]	DNI	DNI	DNI	DNI	DNI	DNI + Diffuse
Concentration Ratio[124]	80	500-1500	500-1500	≤ 80	100-1000	0

118 The annual capacity factor for any given plant is location-specific; a greater solar resource (in $kW/m^2/day$) will result in a higher annual capacity factor.

119 U.S. Department of Energy, April 15, 2008, p. 114.

120 Ausra, Inc., 2007, p. 6.

121 U.S. Department of Energy, April 15, 2008, pp. 43-44 for Parabolic Trough and Dish/Engine; p. 121 for Concentrating PV Commercial Device Efficiency.

122 Industry estimate.

123 Prometheus Institute and Greentech Media, 2008, p. 87 (online) or p. 81 (print).

124 *Ibid*. Concentration Ratio = Area of the Aperture of the Concentrator/Area of the Focal Point. A concentrator with a high concentration ratio will typically generate more heat, but will also require more precise tracking than a concentrator with a lower concentration ratio.

Focus Type[125]	Line	Point	Point	Line	Line/Point	Area
Land Use[126] (acres/MW)	5; 7 (with 6 hours TES)	5	11	3[127]	10	14[128]
Tracking	1-axis (N-S); E-W tracking	2-axis	2-axis	1-axis	1-axis	None
Water Use (gallons/MWh)	72 for dry cooling; 905 for wet cooling[129]	1.9[130]	13.7 for dry cooling[131]; 634 for wet cooling[132]	Same as for parabolic trough, given similar target for steam conditions	Same as for dish/engine, since both need water only for washing	Double CPV (larger PV area due to lack of concentrating optics)

125 *Ibid*. The focus type indicates whether the concentrator focuses light onto a line, point, or area. The focus type determine the type of tracking required and, for concentrating thermal systems, how heat is removed from the focal point and transferred to the power converter. A linear focus type concentrator usually pipes a heat transfer fluid to transfer heat; a point focus type concentrator may either use a heat transfer fluid or convert the heat directly to steam.

126 Navigant Consulting, January 2007, pp. 77, 83, 85, 89.

127 Industry estimate.

128 BBC News, 3/28/07, "Portugal opens major solar plant," http://newsvote.bbc.co.uk/mpapps/pagetools/print/news.bbc.co.uk/2/hi/europe/6505221.stm

129 California Energy Commission, November 2005, p. 48.

130 Calculated based on specifications provided in California Energy Commission, Docket No. 08-AFC-5, for the Solar Two Project at http://www.energy.ca.gov/sitingcases/solartwo/documents/applicant/afc/volume_01/MASTER_Section%205.5.pdf

131 Calculated based on specifications provided in California Energy Commission, Docket No. 07-AFC-5, for the Ivanpah Solar Electric Generating System at http://www.energy.ca.gov/2008publications/CEC-700-2008-013/CEC-700-2008-013-PSA.PDF

132 SolarPaces, "Solar Power Tower" technology primer, p. 5-22, available online at: http://www.solarpaces.org/CSP_Technology/docs/solar_tower.pdf