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LARGE-SCALE SOLAR ASSOCIATION

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DOCKET
09-RENEW EO-1
DATE MAY 10 2010
RECD. MAY 17 2010

May 10, 2010

Submitted via Electronic Mail to: docket@energy.state.ca.us

<u>RE: Comments for Desert Renewable Energy Conservation Plan Science Advisory Panel (Docket No. RENEW EO-01)</u>

Dear Dr. Spencer and members of the Desert Renewable Energy Conservation Plan Science Advisory Panel:

The Large-scale Solar Association (LSA) appreciates the opportunity submit this letter to provide information to the Desert Renewable Energy Conservation Plan (DRECP) Science Advisory Panel (Panel) about solar energy siting requirements and generation technologies.

LSA represents thirteen of the nation's largest developers and providers of utility-scale solar generating resources. Collectively, LSA's members have contracted with utilities in California and the West to provide more than 6 gigawatts ("GW") of clean, sustainable solar power. Our members develop, own and operate various types of utility-scale solar technologies, including photovoltaic and solar thermal system designs. LSA and its individual member companies are leaders in the renewable energy industry, advancing solar generation technologies and advocating competitive market structures that facilitate significant integration of renewable energy throughout the western United States. LSA actively represents the interests of utility-scale solar development in California, Arizona, and Nevada, and also works to shape regional and federal policies that affect solar market development.

LSA appreciates the Panel's efforts to synthesize the existing science on biological resources and ensure that the overall plan to protect and conserve biological resources in the DRECP area is consistent with the scientific literature. In this letter, LSA provides information about solar energy siting constraints and technologies to address questions asked by the Panel during the April 22nd meeting. We invite the Panel to contact LSA if there are additional questions on solar generation that we can address moving forward.

In developing its recommendations for the DRECP, LSA recommends that the Panel:

- Focus on prioritizing areas of biological and ecological importance within the DRECP planning area and developing conservation management principles for the area
- Avoid making specific siting, operations, or technology recommendations for solar generation facilities in the DRECP planning area
- Propose alternative reserve recommendations to allow flexibility in DRECP conservation design to allow for the efficient development of energy resources, which can reduce the overall footprint of energy development in the DRECP planning area and in the surrounding region
- Develop a method for gathering and synthesizing new data and lessons learned in an expeditious manner to allow these lessons and data to be incorporated into future projects

LSA cautions the Panel against weighing in on specific locations to site solar facilities. Dr. Spencer's presentation at the April 22nd workshop identifies "What guidelines are appropriate for siting energy facilities to minimize harm to covered species?" as an appropriate issue for the Panel to address. LSA acknowledges the Panel's expertise in biological issues and habitat needs, and believes the panel should concentrate its focus on the biological and ecological needs of the DRECP planning area. As described in this letter, a number of technical and economic constraints affect the siting of individual solar generation facilities. This letter provides only a broad overview of how these factors constrain the siting of solar facilities.

Finally, LSA recommends that, if specific siting recommendations will be made to the DRECP, these recommendations be developed by an independent panel of renewable energy experts with expertise on how the siting factors described in this letter affect the feasibility and operation of large scale renewable generation. A DRECP-specific renewable energy siting panel could also provide critical input to the planning process by identifying generation sites that will maximize efficient energy production and, thereby, reduce the total footprint of generation and associated impacts to species and ecology both within the DRECP and in other surrounding areas.

I. Need for and Benefits of Large Scale Solar Generation

Since the passage of AB 32 in 2006, California has developed and begun implementing a plan to reduce the state's greenhouse gas (GHG) emissions to 1990 levels by 2020. Meeting this ambitious GHG emission reduction goal will require the state to reduce its GHG emissions across many sectors. The state's Climate Change Scoping Plan identifies a number of opportunities to reduce GHG emissions within the electricity generation sector. Energy efficiency, distributed generation, and increased large scale renewables are the three primary areas within the electricity generation sector to achieve GHG reductions. Specifically, the Scoping Plan quantifies the significant GHG reductions associated with increased energy efficiency standards (26.3 MMT CO2E), the 33% Renewable Portfolio Standard (21.3 MMT CO2E), and the Million Solar Roofs Initiative (2.1 MMT CO2E).[1]

Large scale solar generation has a major role to play in ensuring California achieves the 33% renewable energy by 2020 standard. According to recent studies prepared for the California Air Resources Board, large scale solar resources are expected to be the largest source of new renewable generation in the state.[2] While California expects distributed generation (including rooftop solar) to reduce the overall energy load, these distributed technologies, while important to meeting California's energy needs will not be sufficient to achieve California's ambitious renewable goals. Large scale development of renewable energy resources, including solar, is necessary to meet California's climate and energy goals.

In addition to helping California meet its renewable energy policy goals, large scale solar can provide a number of other environmental and economic benefits to the state. By offsetting conventional natural gas generation, large scale solar will reduce air emissions and the associated health impacts. Economically, large scale solar will help protect California ratepayers from volatile natural gas prices and create both temporary construction and long term operation and maintenance jobs in the state. The chart below[3] monetizes the myriad benefits of large scale solar generation (large scale solar power or LSSP) over a combined-cycle natural gas fired power plant.

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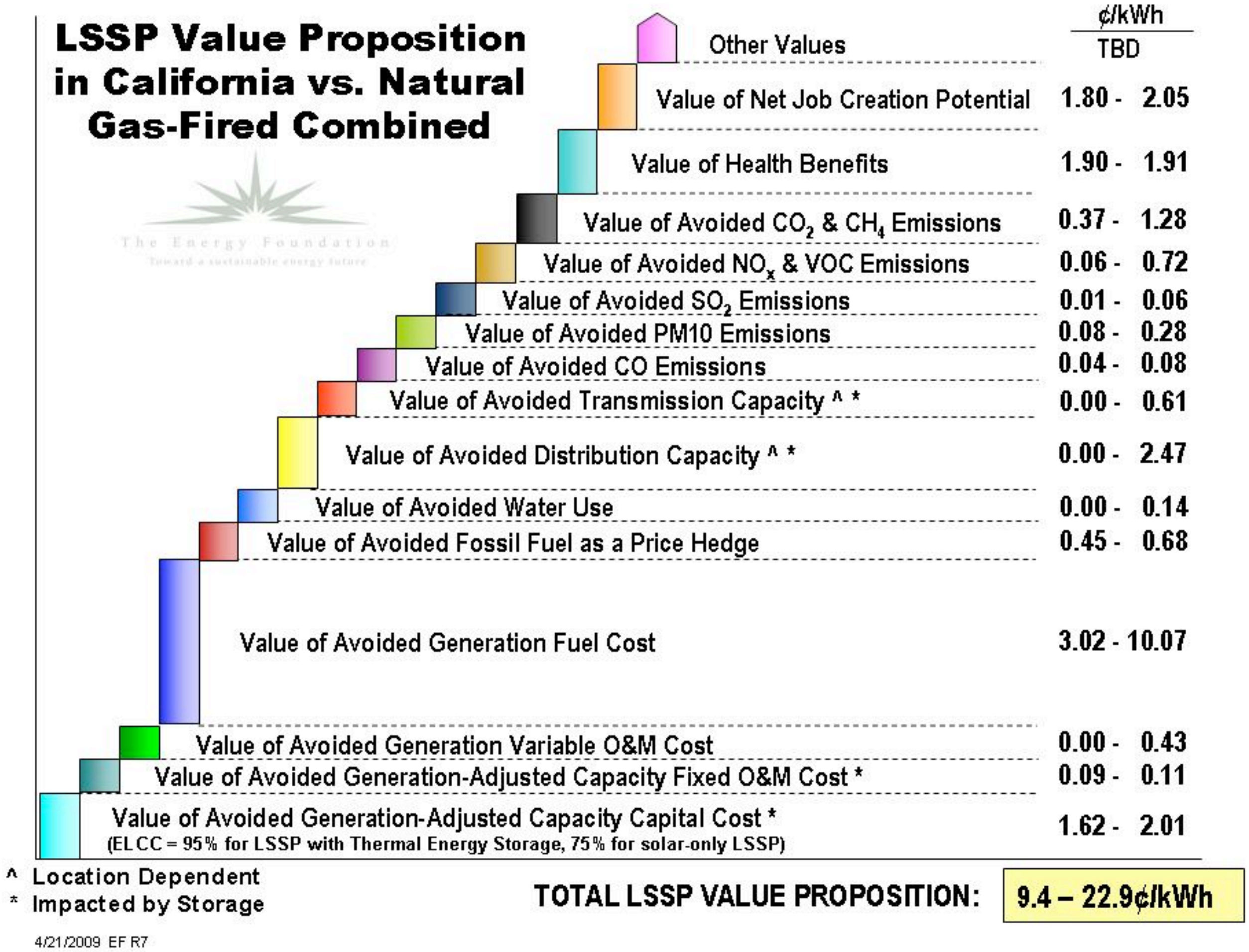
[1] California Air Resources Board, Climate Change Scoping Plan: A Framework for Change, p. 23 (December 2008), *available at* http://www.arb.ca.gov/cc/scopingplan/document/adopted_scoping_plan.pdf.

[2] *See* Status Report: Evaluation of Environmental Impacts of the Renewable Electricity Standard (Preliminary Draft), p. 3 (April 3, 2010), *available at* http://www.arb.ca.gov/energy/res/meetings/040510/eia-whitepaper.pdf.

[3] Excerpted from Lori Schell, Value Proposition of Large-Scale Solar Power Technologies in California – Description of Methodology White Paper, prepared for the Center for Energy Efficiency and Renewable Technology, p. 5 (April 27, 2009).



Although it may appear that simply siting many large renewable projects in a single area would be the easiest solution from a land-use perspective, energy reliability precludes such an approach. Solar and wind facilities have intermittent energy output, meaning that when the sun is obscured or the wind is not blowing, then the facility's generation is diminished. Concentrating many projects in a single area could pose risks to the reliability of the energy grid and reduce the environmental benefits provided by these renewables, because if the solar or wind resource is impaired for any period of time, back-up generation – typically from fossil-fired resources – will be required to ensure smooth grid operations and power delivery. Siting renewables in various locations helps to ensure a more consistent energy delivery profile from renewable facilities across a region, and can reduce the need for fossil-fired generation and its associated emissions.

II. Siting Constraints for Solar Generation

To maximize the benefits of solar generation, the generation facility must be sited carefully. The quality of the solar resource varies significantly, even within the DRECP planning area. However, even in areas of high quality solar resources, choosing a site for a solar generation facility takes into account many factors. These factors include identified environmentally sensitive areas, the terrain, and proximity to existing load and infrastructure. Each of the siting factors is discussed in turn below. Along with this discussion, we provide maps from the National Renewable Energy Laboratory[4] demonstrating how consideration of these factors narrows the area within the Southwestern U.S. and

[4] Maps excerpted from presentation by Mark Mehos, National Renewable Energy Laboratory entitled Overview of Concentrating Solar Power Technologies (dated June 21, 2007)

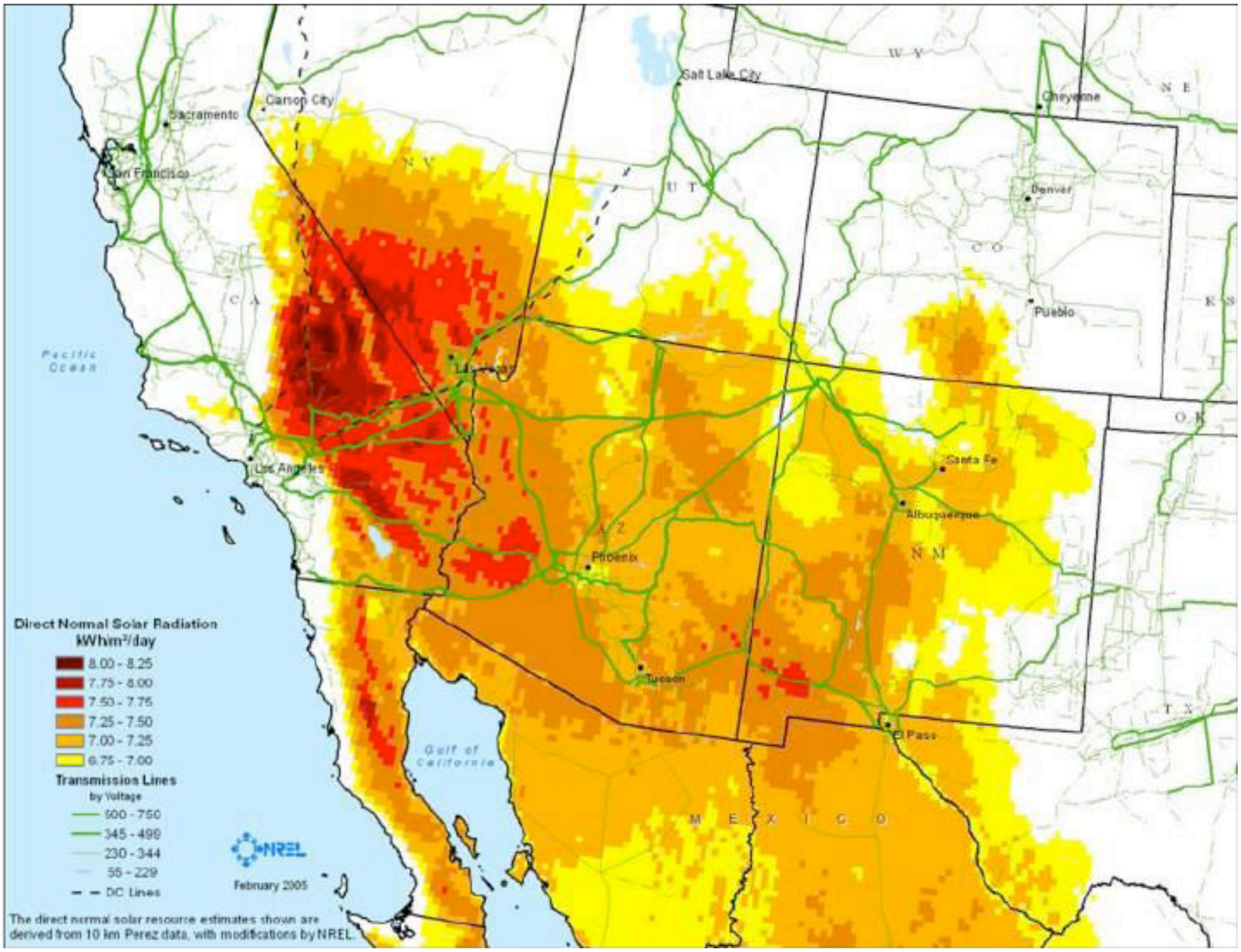
the DRECP planning area that is viable for renewable energy generation. Although the DRECP planning area is quite large, the existing, pre-DRECP siting considerations greatly reduce the area feasible for the development of solar generation.

Similarly, the amount of land needed for solar is much smaller than the area of land set-aside for other uses in the desert. As Ryan Drobek from the Center for Energy Efficiency and Renewable Technologies summarized in his April 22nd presentation, California will need to dedicate 0.05 million acres of land in the California desert to renewable generation to achieve the goal of 33% renewables by 2020. While this is a large area of land, the required land for renewables is still much less than the land set-aside for other uses, including defense department uses (3.3 million acres) and off-highway vehicles (0.7 million acres).

A. Insolation

Insolation is a quantitative measure of the quality of the solar resource for the purpose of solar energy generation. Insolation is the amount of solar radiation on the earth's surface over a given time (often measured in units of kWh/m^2-day). Solar generation facilities sited in areas of high insolation have better efficiencies and lower costs. For siting, solar generators seek areas with insolation greater than 6.75 kWh/m^2-day. However, above this threshold, higher insolation values provide great benefits for solar generators. A reduction of 1 kWh/m^2-day in insolation is equivalent to approximately 10% reduction in efficiency and, in turn, approximately 10% increase in costs and footprint due to the need for additional generating equipment.

The map below, prepared by the National Renewable Energy Laboratory, shows the areas of the Southwest that have insolation values exceeding 6.75 kWh/m^2-day. While all of the yellow and red areas have adequate solar resource for solar generation, the areas that are darker in color have the best solar resource, allowing energy to be produced most efficiently and at the lowest price.

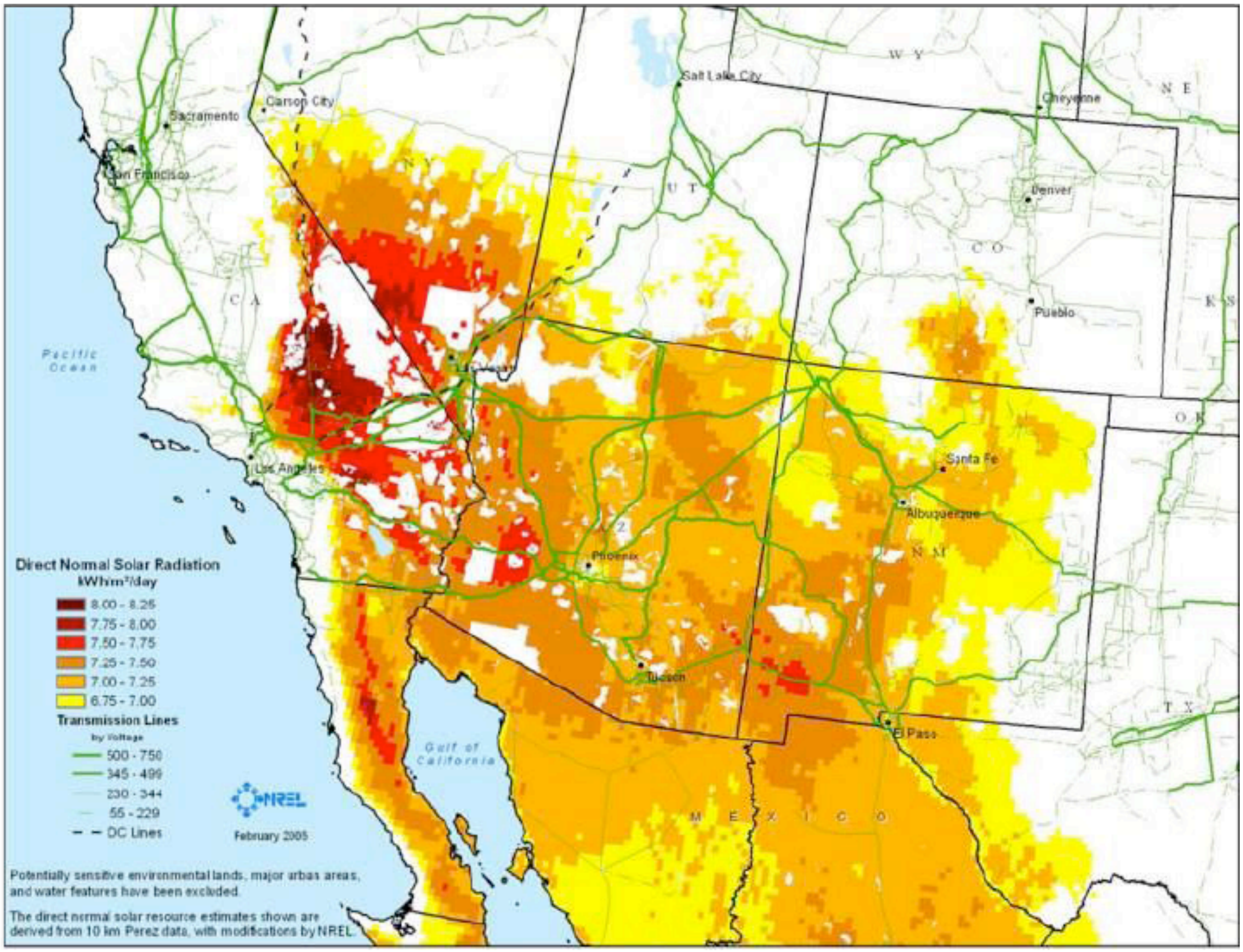


B. Incompatible Land Uses

A second consideration in the siting of solar generation facilities is the existing land uses or restrictions on the land. For instance, solar generation facilities cannot be sited in existing urban areas. Thus, within these areas of high insolation, many areas are incompatible with solar development, based on their use or land use restrictions in place. In addition to urban areas, the Southwest includes large areas of federal land dedicated to national parks and monuments and military facilities, which are similarly incompatible with large scale solar generation. Finally, solar generation facilities must avoid areas that have been designated as protected for environmental reasons.

In the following NREL map, the shading has been removed from areas where solar generation cannot be developed due to conflicting land uses and restrictions. The excluded lands include urban areas, water and wetland features, and all federal lands with special protection status.[5]

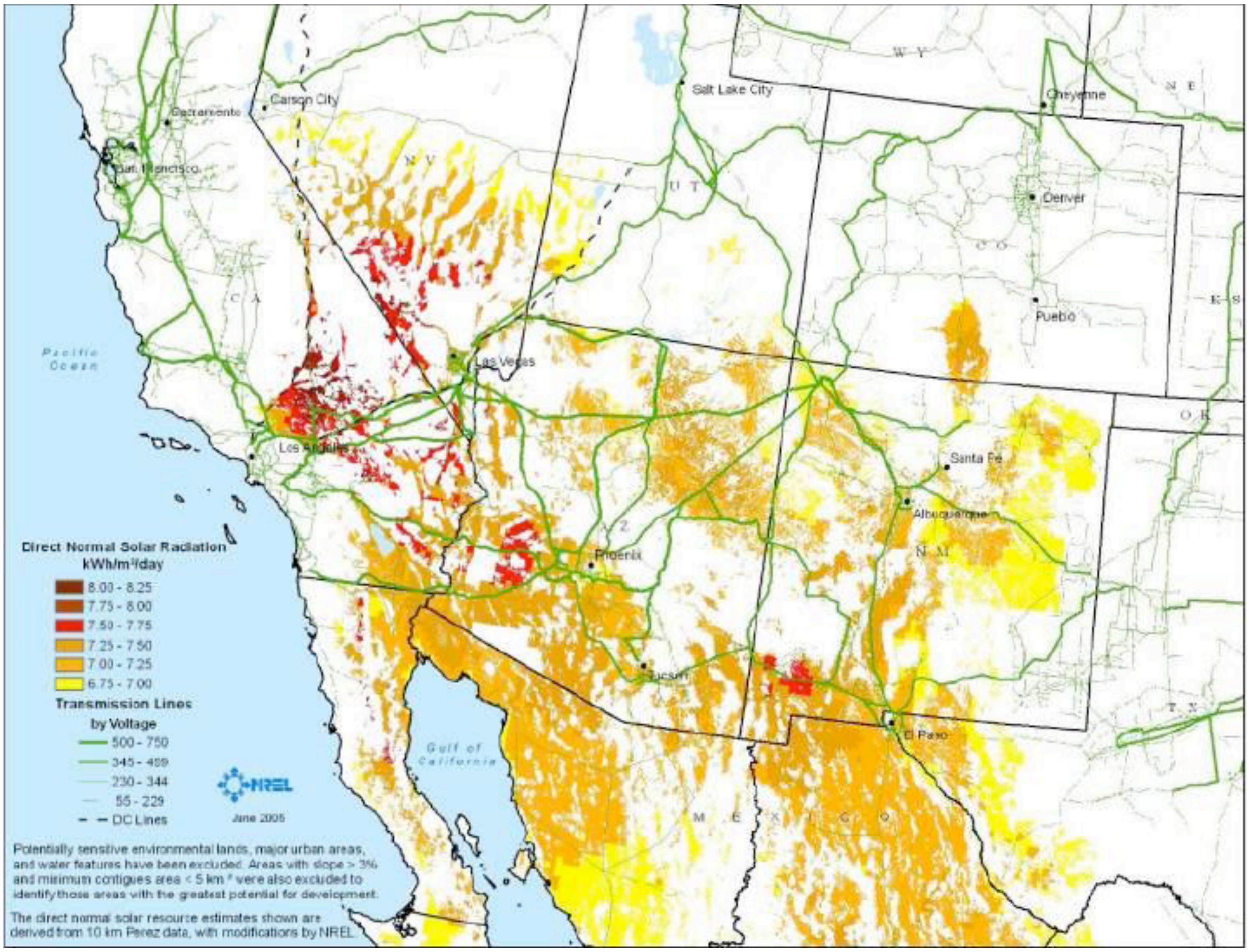
[5] As the land exclusions on the NREL map only take into account federal protections, there may be additional land that cannot be developed in this region based on state environmental protections.



C. Slope

Another factor that dictates the siting of solar facilities is the slope of the land. Most solar generating technologies must be sited on relatively flat ground to ensure that the solar collectors can utilize the solar resource effectively. Typically, solar facilities must be sited on land that has less than 5% slope. Depending on the technology, however, the required slope must be in the range of 3-5%. Lower slopes are generally required for solar generation facilities that use tracking systems to follow the sunlight, as the land must be uniform for the automated adjustment of the solar collectors to function properly and ensure that the sunlight is efficiently harnessed for energy.

The following NREL map removes the shading from areas with greater than 3% slope. This map identifies far less area as suitable for solar development. And, comparing this map with the previous maps indicates that many of the areas with the best solar resource cannot be developed, due to the terrain.



D. Proximity to infrastructure and existing load

Ideally, solar facilities can be sited near existing roads, transmission lines,[6] and other infrastructure. To the extent that lands close to infrastructure are available for development, solar developers will have an economic incentive to site in these locations, as it reduces the overall costs for developing infrastructure to reach and serve the facility. In addition to reducing the development costs, proximity to existing infrastructure reduces the environmental footprint of the generation facility, resulting both in less initial disturbance and, in turn, less mitigation required based on the smaller footprint.

III. Large Scale Solar Generation Technologies

LSA hopes that the following general information on generation technologies will provide the Panel helpful background on renewable generation as they move forward with making their recommendations. Without additional input from solar generation experts, LSA urges the Panel not to make technology-specific recommendations or weigh in on the compatibility of specific technologies

[6] The NREL maps show existing transmission lines in the region. However, these maps do not indicate the amount of capacity remaining on these lines. Transmission lines that are fully subscribed do not offer the same siting benefits as those which have capacity to transmit additional energy.

with biological goals.

Large scale solar generation includes a number of technologies, some of which were discussed in the April 22nd presentation by Craig Turchi from the National Renewable Energy Laboratory. Solar energy technologies fall into two general categories: solar thermal and photovoltaics. Solar thermal technologies harness and concentrate the heat from the sun to generate electricity. Photovoltaics, on the other hand, convert light from the sun into electricity. Within both of these categories, there are several different generation technologies. The primary solar generation technologies are described below. Attached to this letter is an excerpt of a white paper that describes these technologies in more detail.[7]

A. Solar Thermal

Dr. Turchi's presentation focused on concentrating solar thermal technologies.[8] These technologies Dr. Turchi discussed were all concentrating solar thermal technologies, which concentrate the sun's rays on medium that absorbs heat. These technologies use different mechanisms for transforming this thermal energy into electricity, as described below.

a. Parabolic Trough

Parabolic trough generation facilities contain a solar field with long parallel rows of trough-shaped mirrors, typically aligned in north-south orientation. These parabolic mirrors are designed to track the sun and reflect the sun's rays onto a central tube passing through the trough, which contains heat transfer fluid.[9] The transfer fluid is heated as it travels through the array of troughs and is pumped to a central power block, where the heat energy is converted to steam through a series of heat exchangers. Once the steam is generated, the power generation process is essentially the same as a conventional steam generation plant.

b. Compact Linear Fresnel Reflector

Compact Linear Fresnel Reflector (CLFR) generation technology is similar to a parabolic trough in that CLFR consists of a field of mirrors that focus sunlight on receiver tubes passing above the mirrors. However, for CLFR, the mirrors are flat and the receiver tubes contain water that is converted to steam in the generation field. The superheated steam generated in the receiver tubes is used to drive a conventional steam turbine housed in a central power block to generate electricity.

c. Parabolic Dish-Stirling Engine

Parabolic Dish-Stirling Engine generation facilities consist of a series of parabolic dishes (similar to satellite dishes), each of which focuses sunlight on an individual receiver located at the focal point of the dish. The receiver typically contains a heat transfer medium (commonly either hydrogen or helium gas) that expands as it is heated and moves pistons or a turbine. This mechanical movement, in turn, drives a generator and produces electricity.

d. Power Tower

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[7] Attachment A is an excerpt of an April 27, 2009 white paper prepared for the Center for Energy Efficiency and Renewable Technologies (CEERT) by Lori Schell entitled "Value Proposition of Large-Scale Solar Power Technologies in California – Description of Methodology."

[8] Note – concentrating photovoltaic technologies also exist, but commonly concentrating solar power or CSP refers to solar thermal generation.

[9] Common heat transfer fluids include: synthetic oil, water, and, more recently, molten salt.

Power tower generation facilities consist of a field of tracking mirrors (heliostats) that follow the motion of the sun and direct sunlight onto a receiver at the top of a single central tower in the field. The receiver atop the central tower contains a heat transfer fluid that, once heated, is used to generate steam and produce electricity as in a conventional steam-turbine power block.

B. Photovoltaics

Photovoltaics use a process to convert sunlight directly into electricity, known as the photovoltaic effect. Certain materials (semiconductors) are able to absorb the energy from sunlight, releasing electrons. These released electrons create an electric current.

a. Flat Panel Photovoltaic

Flat panel photovoltaics are generally made of a layer of silicon, a semiconducting material placed under nonreflective glass. When sunlight hits the silicon, the light energy is absorbed by the silicon, which releases electrons. The flow of electrons through the material produces direct-current electricity. The current is directed to a converter, which turns it into alternating current. The alternating current can then be fed into the grid and delivered as electricity.

b. Thin Film Photovoltaics

Thin film photovoltaics use the same principles as flat panels to create electricity. The primary difference is that thin film photovoltaics use semiconducting materials with a higher rate of light absorption than the silicon used in flat panels. These materials allow for thicknesses approximately 100 times thinner than flat panel silicon cells.

c. Concentrating Photovoltaic

Concentrating photovoltaics use high efficiency semiconductors with solar trackers and reflective or refractive optics. The addition of these trackers and optics increases the power output while simultaneously reducing the size or number of solar cells needed.

IV. Solar Resources in the DRECP Area

LSA encourages the Panel to review and take into account the current work identifying the areas most suitable for solar generation facilities. This includes on-going efforts by the Bureau of Land Management to prepare the Solar Programmatic Environmental Impact Statement, including the identification of Solar Energy Study Areas and Solar Energy Zones,[10] and work by the Renewable Energy Transmission Initiative (RETI) to identify Competitive Renewable Energy Zones (CREZs) and the transmission corridors needed to deliver energy generated within those CREZs to consumers.[11]

In closing, LSA urges the Panel to focus on developing criteria that will allow for some flexibility in reserve design to ensure that generation facilities can be sited in a manner that minimizes biological and ecological impacts, while allowing for efficient energy production. Thank you for the opportunity to submit this letter. Please feel free to contact me if you have any questions about these comments.

[10] For information on BLM's Solar Energy Development PEIS, see http://solareis.anl.gov/.
[11] For information on the Renewable Energy Transmission Initiative's work to date, see http://www.energy.ca.gov/reti/documents/index.html.

Sincerely,

________/s/___________
Shannon Eddy
Executive Director

Attachments:
Attachment A: Lori Schell, *Value Proposition of Large-Scale Solar Power Technologies in California – Description of Methodology* White Paper prepared for the Center for Energy Efficiency and Renewable Technology, Appendix A (April 27, 2009)

Attachment A: Excerpt of Lori Schell, Value Proposition of Large-Scale Solar Power Technologies in California – Description of Methodology White Paper (April 27, 2009)

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.[12]

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.[13] 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.[14] 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. [15]

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 States on a flat, horizontal surface is roughly 3.0-5.8 kWh/m^2/day.[16] 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

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

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

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

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

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

greater than a 3% slope, as shown below in Figure A-1.

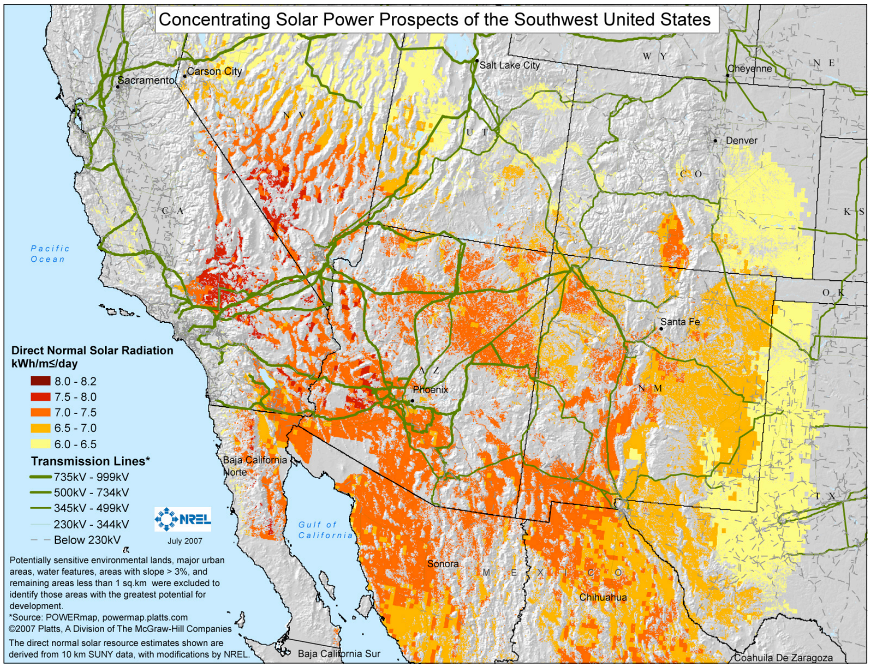

Figure A-1. Annual Average Direct Normal Insolation, Land with ≤3% Slope (Source: National Renewable Energy Laboratory)

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.[17]

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.[18]

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17 U.S. Department of Energy, February 7, 2008, p. 6 and p. 36.

18 ECOSTAR, p. 39.

Parabolic Troughs[19] [20] [21] [22]

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)[23] 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.

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

19 U.S. Department of Energy, April 15, 2008, p. 114 and p. 117.

20 European Commission, 2007, p. 9.

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

22 http://www1.eere.energy.gov/solar/linear_concentrator_rnd.html

23 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.

efficiency and reducing the installed capital cost of the solar field, including the concentrator and solar receiver.[24]

Dish/Engine Systems[25]

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.[26]

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 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.[27]

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.[28] 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.[29]

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.[30] Similarly, efforts are underway to hybridize large dish/engine systems with natural gas firing to increase the ability of such

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[24] U.S. Department of Energy, April 15, 2008, p. 117.

[25] http://www1.eere.energy.gov/solar/dish_engines.html

[26] U.S. Department of Energy, February 5, 2007, p. 20.

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

[28] Renewable Energy Focus, January/February 2008, p. 44.

[29] U.S. Department of Energy, April 15, 2008, p. 118.

[30] U.S. Department of Energy, September 19, 2008, p. 2.

systems to provide dispatchable power.

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

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).[31]

Power Towers[32]

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.[33]

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31 U.S Department of Energy, February 2007, p. 8.

32 http://www1.eere.energy.gov/solar/power_towers.html

33 U.S. Department of Energy, April 15, 2008, p. 115.

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

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.[34] 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.[35] 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.[36] 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. [37]

The simple structure of the flat mirrors in linear Fresnel systems lends itself to mass

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

[35] Renewable Energy Focus, January/February 2008, p. 44.

[36] http://www.spg-gmbh.com/index.asp?document_id=161

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

production, and these structures are considerably lighter than the concentrating structures of parabolic troughs, dish/engines, and power towers.[38] Linear Fresnel systems have higher intrinsic optical losses compared to parabolic trough systems,[39] but manufacturers believe that the lower optical performance will be offset by lower investment costs in the collectors due to the more-standardized components.[40]

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

Non-Concentrating Photovoltaics[41]

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.,

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

39 ECOSTAR, 2005, p. 47.

40 ECOSTAR, 2005, p. 132.

41 U.S. Department of Energy, April 15, 2008. p. 111-113.

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.

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.[42] 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.[43]

[42] U.S. Department of Energy, February 7, 2008, p. 18.

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

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

Concentrating Photovoltaics[44] [45]

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;[46] 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.[47]

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

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

[46] 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

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

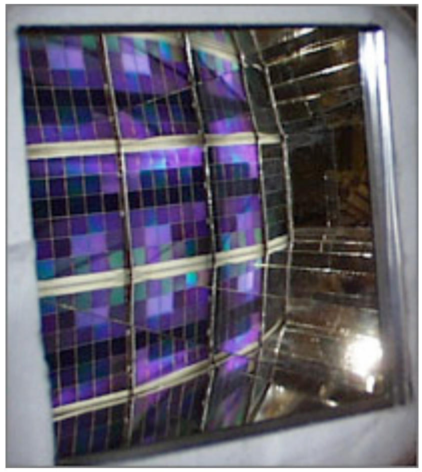

Figure A-8. Concentrating Photovoltaics: Dense Array of High-Efficiency Silicon Cells (Source: National Renewable Energy Laboratory)

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.[48]

[48] CPV Today, November 24, 2008.