CHAPTER 3 | UTILITY-SCALE SOLAR TECHNOLOGIES

The type of technology chosen for a utility-scale solar project influences a project's efficiency as well as its ecological impacts. This chapter describes in detail the various technologies currently proposed in right-of-way applications as well as several that are currently in development. Also included is a discussion of the key considerations project developers take into account when selecting the type of technology to be used for a utility-scale solar project. Subsequent chapters will focus on the ecological impact implications of these utility-scale facilities.

SOLAR TECHNOLOGIES

Of the 54 right-of-way applications the BLM is currently reviewing for approval, roughly 60 percent call for the use of concentrated solar power (CSP), also referred to as solar thermal power, and the other 40 percent propose the use of PV technology.[1] There are three main types of CSP technologies (parabolic trough, power tower, and dish/engine), and three main types of PV technologies (flat plate, thin film, and concentrating PV) developers consider when scoping a utility-scale solar project. These systems are ideal for bulk electricity generation because they are designed to produce power on a utility scale, which is orders of magnitude greater than distributed generation or rooftop systems. While there is currently no set definition of utility-scale solar, these facilities generally have a nameplate capacity of over 50 MW and produce electricity that is fed back into the electric grid. In order to generate this amount of power, utility-scale solar power plants require large parcels of land along with access to either surface or groundwater, especially if the facility has an associated cooling system. A value called the capacity factor is used to describe the overall efficiency of a power generation facility. The capacity factor is defined as the ratio between the actual output of a power plant and the maximum rated output, or nameplate capacity. It is calculated by measuring the total energy produced over a period of time and dividing by the amount of energy the plant would have produced over the same period of time at full capacity. For CSP and PV plants, the capacity factor is dependent primarily on the availability of the sun's energy over a given period.

What follows are detailed descriptions of the various solar technologies mentioned above, including a discussion of various cooling system types developers are considering for use in utility-scale facilities. A complete list of utility-scale solar projects in operation or development for the region is included in Appendix B.

Concentrated Solar Power (CSP)

Parabolic Trough

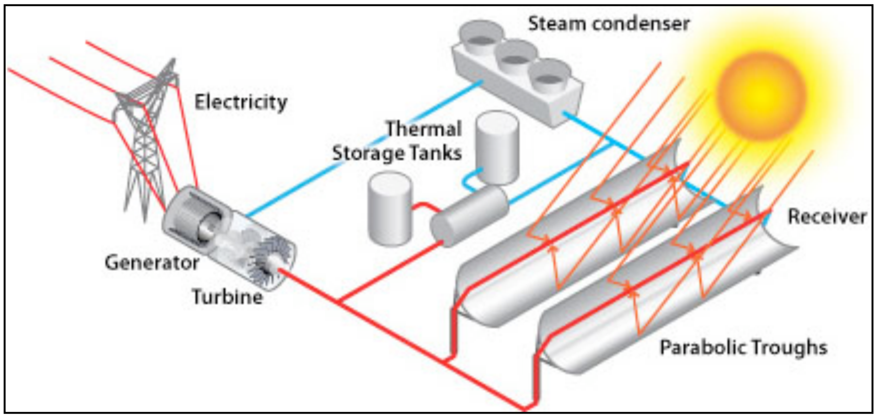


Figure 3.1 Linear Concentrator Power Plant Using Parabolic Trough Collectors. Source: U.S. Department of Energy. http://www1.eere.energy.gov/solar/linear_concentrators.html.

As was mentioned earlier, roughly 60 percent of the applications under review by the BLM call for the use of a parabolic trough system (Figure 3.1). These systems are composed of long parabolic shaped mirrors, a receiver tube that runs the length of the mirrors, a tracking support structure and drive components that control the movement of the collector throughout the day in relationship to the position of the sun. Altogether these components are called a solar collector assembly (SCA). The SCA's can sit approximately 25 to 30 feet above ground. The parabolic mirrors are made of 4-millimeter thick glass with high transmittance properties and include a reflective silver layer on the backside of the glass.[2] The mirrors are shaped in a parabola such that the sun's light is directed to a focal point where the energy is concentrated onto to the linear receiver, or heat collection element (HCE). The HCE is a stainless steel tube with a specific diameter and is coated with a special solar-selective absorber surface to maximize efficient transfer of heat from the sun's energy to the heat transfer fluid (HTF) traveling inside the tube. The HTF is usually comprised of a either a high-temperature oil or a mixture of water and ethylene glycol.[3] The heated transfer fluid is supplied to the power plant where it passes through a series of heat exchangers, turning water into high-pressure steam that drives a Rankine steam turbine. The HTF is then returned to the solar collector field to be heated once again, creating a closed loop system. Parabolic trough plants achieve at least a 25 percent[4] capacity factor, which means about a quarter of the sun's energy that is captured by the system is converted to usable electricity.

Power Tower

There are also several applications in with the BLM that call for the use of Power tower systems (Figure 3.2). These systems use a large field of mirrors called heliostats that track the sun and concentrate the light onto a central receiver on top of tower. Tower heights range from approximately 300 to 650 feet. Tower height and field size vary depending on individual project economics. An economic optimization analysis takes into consideration the capacity factor and capital costs. The amount of solar energy collected is a function of the number of heliostats installed. However, as the number of installed mirrors increases, the height of the tower must also increase. Determining the optimal tower height

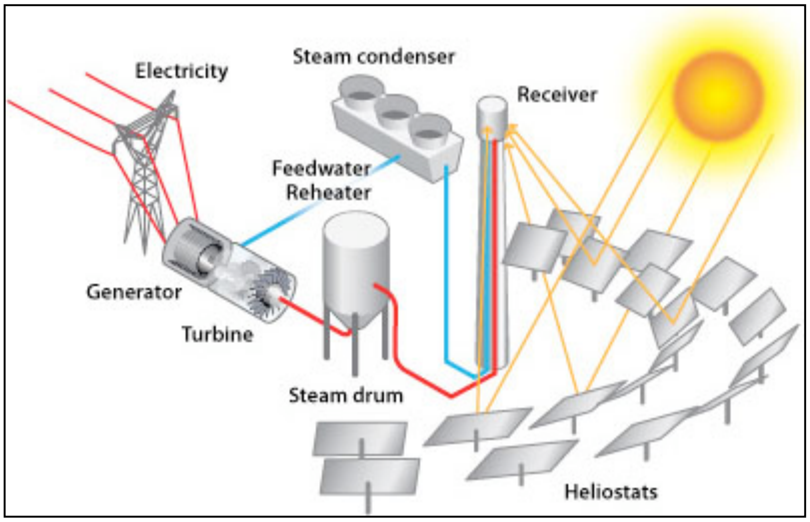


Figure 3.2 Power Tower Power Plant. Source: U.S. Department of Energy. http://www1.eere.energy.gov/solar/linear_concentrators.html.

and field size is driven by economies of scale. It is relatively inexpensive to increase equipment size once a project has incurred its initial fixed costs of installation. Larger plants, therefore, tend to be more economical. Additionally, the heliostats can be mounted in ground with up to five percent slope because they do not rely on a linear collector to heat the HTF. Like the parabolic trough systems, HTF is an integral part of the power tower system. The HTF is composed of either water or molten nitrate salt and as it moves through the receiver it is heated to temperatures over 500 °C. The heated HTF is then sent to a heat exchanger where water is turned into steam, which then drives a turbine generator. More advanced systems that use molten salt as the HTF can take advantage of the higher heat capacity of the fluid and can store the heat energy, which allows the system to continue to generate electricity during cloudy weather or at night. Thermal storage allows systems to continue to generate electricity for several hours longer compared to those without, which effectively increases a power tower's capacity factor from 34 to over 40 percent.[5] Additionally, power tower systems typically employ dry cooling as opposed to wet cooling technology, requiring less water to operate the plant.

Dish/engine

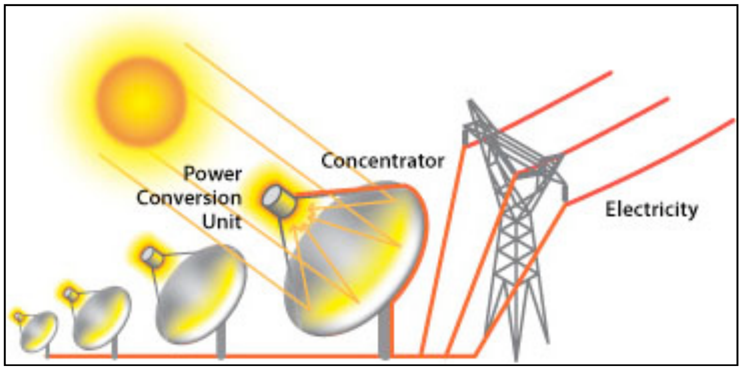


Figure 3.3 Dish Engine Power Plant. Source: U.S. Department of Energy. http://www1.eere.energy.gov/solar/linear_concentrators.html.

There are also a few applications in with the BLM that call for the use of dish/engine systems (Figure 3.3). These systems consist of a large mirrored dish (also known as a solar collector), a receiver, and a small engine. The dish is mounted on a tracking system that follows the sun throughout the day and focuses sunlight onto the receiver. The receiver consists of a series of tubes that are filled with a heat transfer medium. The medium is usually either hydrogen or helium. Concentrated sunlight heats the fluid in the receiver and transfers energy to the engine. A Sterling engine is the most common type of heat engine used in dish/engine systems.

These systems use the heated fluid to move pistons and create mechanical power. The mechanical power is then used to run a generator to produce electricity.[6] The waste heat from the engine is dissipated by a radiator system similar to one found in a car. The cooled medium is then recycled to the engine and the process repeats. To date there are no large installations of dish/engine systems in operation and therefore a capacity factor figure is not available. However, a leading Sterling engine system manufacturer has achieved a dish/engine system efficiency of about 31 percent.[7] Using this value as a proxy, a comparison of capacity factors of the various concentrated solar power technologies is summarized in Table 3.1.

Table 3.1 Concentrated Solar Power Technology Efficiency Comparison.

Technology Type	Capacity factor (%)
Parabolic Trough	25
Power Tower	34
Dish/Engine	31

Linear Fresnel lens

One technology that should be monitored, but does not yet appear in any applications, is a Linear Fresnel reflector systems (Figure 3.4). These systems are similar to parabolic trough systems in that a set of mirrors reflects the sun's energy onto a linear receiver. The major difference is that with a Fresnel system the mirrors are either flat or slightly curved and are mounted on a tracker that focuses the sun light onto a fixed receiver tube system that sits above the mirrors. A central receiver, the tallest component in this system, rises approximately 50 feet above the ground. Few power plants using this technology have been installed and therefore little data is available related to plant efficiency and operational reliability. However, with efficiency improvements on the horizon, more attention is being given to this technology.[8] Linear Fresnel systems have lower production costs due to the use of flat mirrors compared to the curved mirrors used in parabolic trough systems. Another major difference is that water can be converted directly into steam in the long receiver tubes, negating the need to install additional heat exchange equipment. If the plant economics are found to be favorable or if linear Fresnel plant efficiencies can be increased to a point where it is comparable to

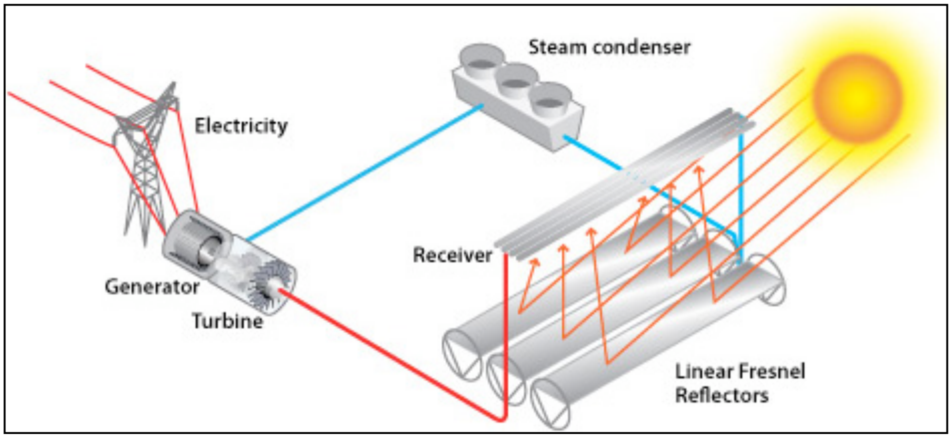


Figure 3.4 Linear Fresnel Reflector Power Plant. Source: U.S. Department of Energy. http://www1.eere.energy.gov/solar/linear_concentrators.html.

parabolic systems, then these systems may become the dominant technology type found in utility-scale solar plant facilities.

Photovoltaic (PV)

Roughly 40 percent of the applications submitted to the BLM call for the use of photovoltaic technology. Photovoltaic power generation is one of the cleanest and environmentally benign methods of generating electricity. During operation, it does not produce emissions or hazardous waste and does not consume water. These types of systems are attractive to utility power providers because they are generally easier to construct and install compared to conventional fossil or nuclear power plants. They can also be more easily expanded as demand increases. The two main types of PV technologies that are being considered for utility-scale solar power generation today are flat plate and thin film PV.

Flat Plate Photovoltaics (PV)

According to the DOE, the most common solar array designs use flat plate PV modules (Figure 3.5).[9] Flat plate PV modules are used in fixed systems or integrated into more sophisticated designs that include tracking systems that follow the sun's trajectory across the horizon throughout the day. Flat plate PV devices can be made of various types of semiconductor materials, the most common of which is silicon. Silicon can be single (or mono)-crystalline, multicrystalline or amorphous. Crystallinity is a measure of how perfectly ordered the atoms are in the crystal structure. Most flat plate PV modules use solar cells that are made from either single-crystalline or amorphous silicon. Single-crystalline silicon is composed of a very uniform crystal structure and is ideal for conducting electrons through the material. Solar cells made from this type of silicon are usually more efficient but also tend to be the most expensive because of the purity of silicon material. Solar panels that utilize amorphous silicon solar cells are currently the most common and are usually cheaper; however, they yield lower energy conversion efficiency. To date, crystalline silicon-based flat plate PV technology is able to achieve module conversion efficiencies between 15 and 20 percent.[10] Module conversion efficiency is a measure of how effectively the sun's energy is converted directly to electricity by the collection of solar cells that make up a single modular unit. At these performance levels, some solar companies have determined that there is a business case for developing large utility-scale solar facilities using flat plate PV technology.

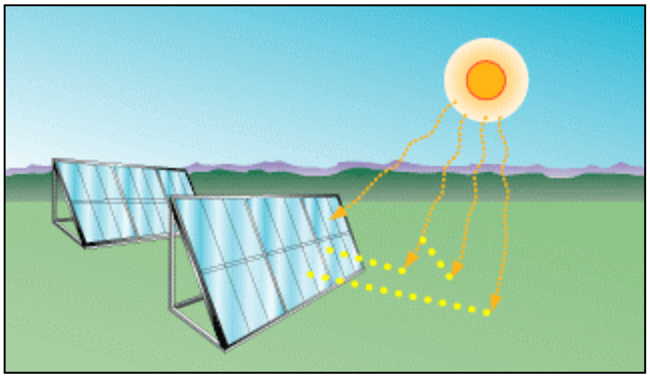


Figure 3.5 Flat Plate Photovoltaic Modules. Source: U.S. Department of Energy. http://www1.eere.energy.gov/solar/linear_concentrators.html

Thin Film PV

Figure 3.6 Nanasolar Thin Film Solar Cells. Source: Nanosolar http://www.nanosolar.com/technology/technology-platforml.

Thin film photovoltaic cells (Figure 3.6) are usually made of a certain type of polycrystalline material. The three most common thin film materials are amorphous silicon (a-Si), copper indium diselenide (CIS) and its alloys, or cadmium telluride (CdTe).[11] Thin film solar cells are produced by depositing very thin consecutive layers of atoms on a flexible substrate. Substrate material can be either glass, stainless steel or various types polymers. Thin films use much less material during production compared to silicon-based solar cells and can be manufactured in large-area automated continuous-process equipment. One method of production employs roll-to-roll printing technology which further reduces the cost of manufacturing. Thin film production costs approximately half that of silicon-wafer based solar cell production.[12] The trade off is that thin film PV cells are significantly less efficient compared to single or amorphous-crystalline silicon solar cells. CdTe based thin film solar cell module efficiency is currently around 13 percent[13], the highest of the three material types. CIS produce modules with an efficiency around 10 percent and a-Si around 8 percent.[14] However, research and development in this area is constantly pushing the efficiency of thin film solar cells closer to that of conventional silicon based PV.

Concentrating Photovoltaic (CPV)

Several concentrating photovoltaic system companies are developing technology that can also be used for utility-scale solar electricity generation, however, none of the applications currently proposed for BLM land call for this technology. CPV systems (Figure 3.7) employ either a large dish of reflective mirrors or concentrating lenses that direct sunlight onto a photovoltaic surface which produces electricity directly from the sun's energy. Either module is installed on a high-precision dual-axis tracking system which ensures optimal operation throughout the day. These

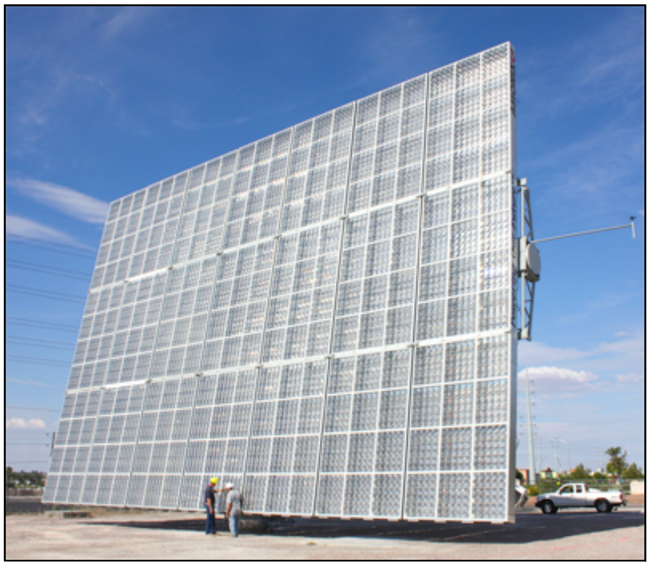


Figure 3.7 Amonix Solar Concentrating PV Module. Source: Amonix Solar http://www.amonix.com/products/index.html.

systems can be configured to concentrate the sun's energy between two to 500 times. High concentration PV (HCPV) systems favor the use of high efficiency, multi-junction solar cell technology because efficiency of these cells rises faster with concentration than do conventional silicon based solar cells. CPV systems have only recently been installed in utility-scale facilities, and therefore system reliability and lifetime performance data is sparse. However, commercially available CPV systems have demonstrated energy conversion efficiencies of approximately 29 percent.[15] A comparison of module efficiencies of the various photovoltaic technologies is summarized in Table 3.2.

Table 3.2 Photovoltaic Solar Technology Efficiency Comparison.

Technology Type	Module efficiency (%)
Flat Plate PV	15
Concentrating PV	29
Thin Film	
CdTe	13
CIS	10
a-Si	8

COOLING SYSTEMS

Solar power plant operation relies on water for a number of functions, but none is as intensive as the cooling system. The amount of water consumed largely depends on the type of cooling system technology employed: wet, dry, or hybrid. Of the eight applications currently under review by the BLM that propose the use either parabolic trough or power tower technology, three plan to install "wet" cooling systems while the other five remaining plan to install "dry" cooling systems. Parabolic trough and power tower technologies use the power of the sun to drive steam turbine generators which necessitate the use of a cooling system to complete the power generation cycle. Dish/engine and photovoltaic systems, on the other hand, generate electricity directly from the sun's energy and therefore do not require the use of a cooling system during operation. The main source of water consumption for these systems is related to mirror washing.

Wet Cooling

Wet cooling tower (also called "Evaporative cooling" or "Wet re-circulating")

Wet cooling systems (Figure 3.8) are the most common technology in new power plants.[16] Waste heat is dissipated to air via evaporation of cooling water. The difference between the wet bulb temperature of the liquid and the dry bulb temperature of the surrounding air determines the potential for evaporative cooling. Consequently, a greater difference between these two temperatures results in greater evaporative cooling effect. This thermodynamic property is the reason why wet cooling systems perform better in areas with high ambient temperatures greater than 110 °F, compared to air cooled systems. These systems withdraw between 300 and 700 gallons per MWh, but all of the water

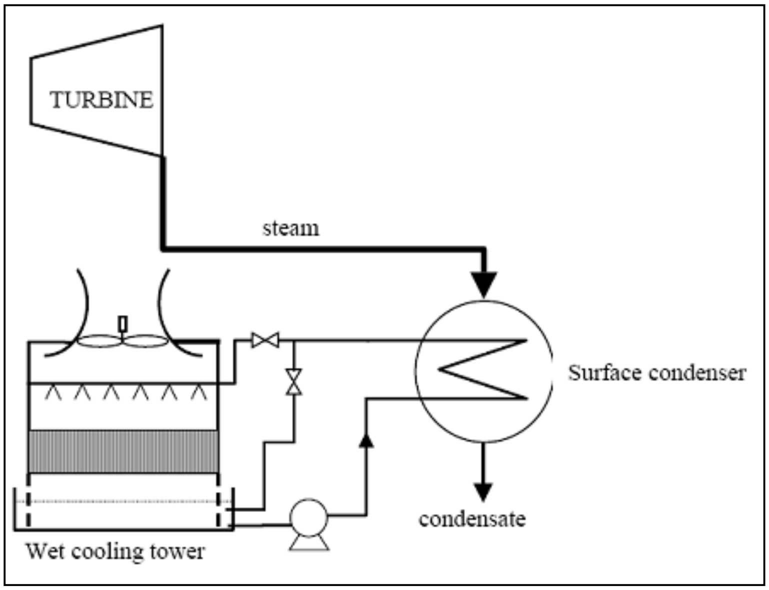


Figure 3.8 Schematic of Wet Cooling System. Source: U.S. Department of Energy.

withdrawn is consumed.[17] The water treatment chemicals and minerals found in the cooling water become more concentrated as the re-circulated liquid evaporates over time. In order to remove particulates and reduce the concentration of salt in the water found in the catch basin, part of the water is discharged (called “blowdown”) and replenished (called “makeup water”) from either surface or ground water supplies. The blowdown is collected in evaporation ponds, which are double-lined to reduce the risk of contaminated water leakage. Some applications include pond designs that do not require the removal of residual solids over the life of the power generation plant. Others account for periodic removal and land-fill disposal of the solids. Several applications call out more specific design requirements that are in accordance with the local Water Quality Control Board. Details include:

- 60 millimeter thickness liner
- High density polyethylene material
- Synthetic drainage net between double lining as part of the leachate collection and removal system (LCRS)

Monitoring of these ponds to detect the presence of liquid and/or constituents of concern is also required according to the CEC. Some applications call out monitoring of the LCRS along with sampling from existing onsite wells. Constituents of concern that are to be monitored include chloride, sodium, sulfate, TDS, biphenyl, diphenyl oxide, potassium, selenium and phosphate.

Once-through

Clean Water Act regulations prohibit the use of once-through cooling for new power plants due to environmental concerns[18] and are not relevant for this context of new solar development in California, and therefore, are not discussed in detail in this report.

Dry Cooling

Air cooled condenser (ACC)

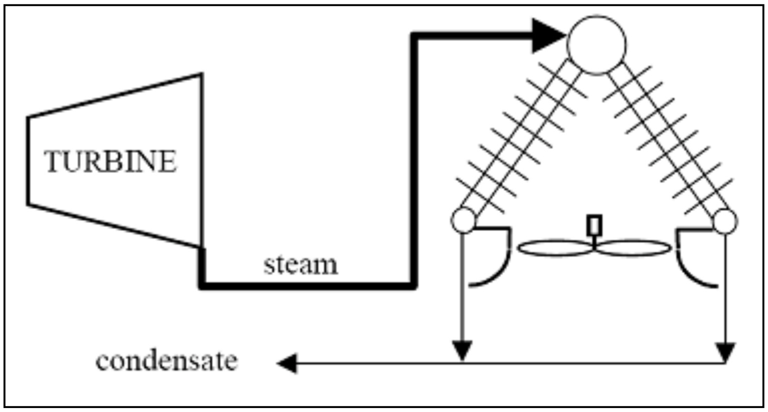


Figure 3.9 Schematic of Dry Cooling System. Source: U.S. Department of Energy.

Dry cooling systems (Figure 3.9) can be categorized as either direct or indirect. Air cooled condensers (ACC) are an example of a direct dry cooling system. For ACC systems, steam from the turbine is routed directly to an array of A-framed tubes and a fan blows air directly across the array, convectively condensing the steam.[19] Dry cooling systems use approximately 95 percent less water than wet systems[20], and are becoming more common in thermal power plants. But they require higher capital costs, higher auxiliary operating power, and result in lower overall power plant performance, especially on hot days when peak power is needed most.[21] According to one study by the National Renewable Energy Laboratory, dry cooling systems impose a seven to nine percent penalty on the levelized cost of energy.[22]

Indirect dry cooling (Heller System)

Indirect cooling, or Heller systems use air as a secondary cooling medium. The primary cooling medium is still water, but the cooling water flows in a closed system and is never in contact with the cooling air. The heat transfer between air and cooling water is achieved with convection rather than evaporation as in wet cooling systems. An additional advantage is that Heller Systems do not require makeup water and have been found to consume roughly 97 percent less water than wet cooling systems with minimal impact on plant performance - roughly one percent increase in levelized cost of electricity.[23] The tradeoffs are a higher initial investment cost and higher long term operating costs.

Hybrid Cooling

Though largely not used in the United States, hybrid systems (Figure 3.10) involve both wet and dry units that run in parallel or use water to cool air going to the air-cooled condenser. In a parallel cooling system, the dry unit is the primary heat rejection system and is used exclusively for the majority of the time during operation.[24] When the ambient air temperature reaches higher temperatures typical of a summer day in the desert Southwest, part of the steam leaving the turbine generator is routed to a wet cooling unit. By reducing the load on the air-cooled condenser, the dry unit can bring the condenser steam temperature closer to the design condenser temperature on hotter days.[25] Hybrid systems have

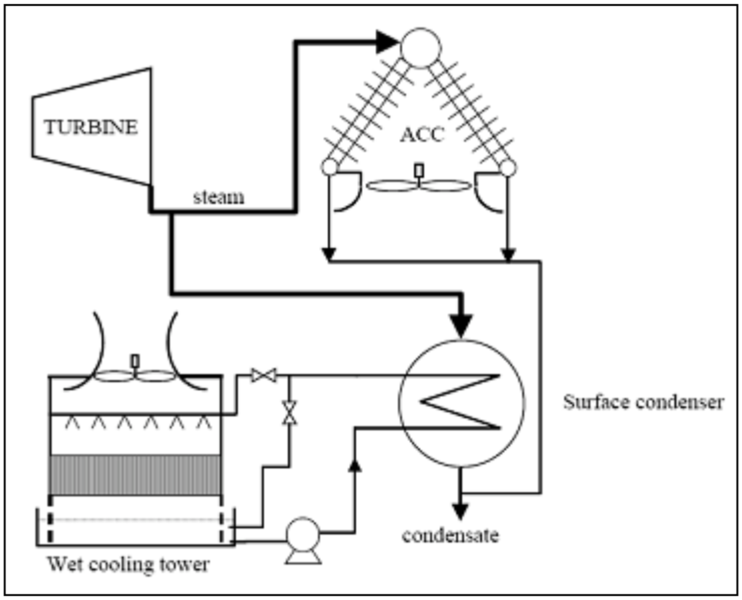


Figure 3.10 Schematic of Hybrid Cooling System. Source: U.S. Department of Energy.

been found to reduce water consumption by 50 percent with only a one percent drop in annual electricity output.[26] Hybrid systems that reduce water consumption compared to wet cooled systems and provide enhanced performance in warmer climates compared to dry cooled systems are of great interest for CSP applications. Hybrid cooling systems aimed at plume abatement involve the reduction of the water vapor plume from a cooling tower to eliminate the appearance of the plume or to avoid winter icing on nearby roads.[27] This is less of a concern for CSP systems in the arid climate of the Southwestern United States.

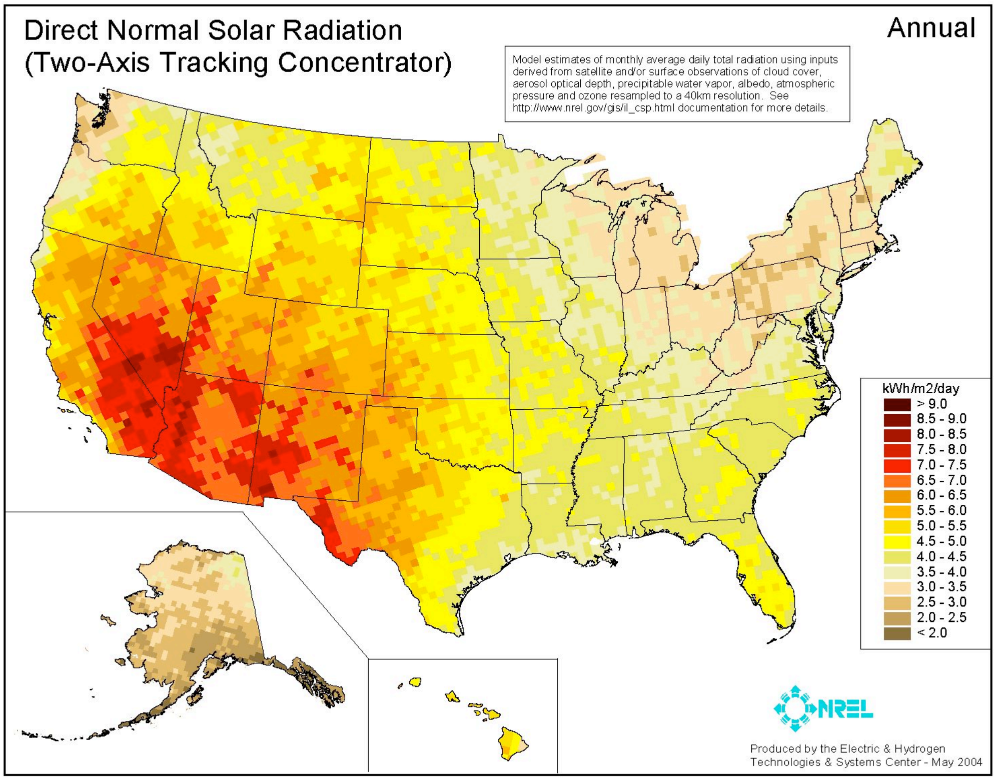
KEY CONSIDERATIONS OF DEVELOPERS

Over the course of nine interviews we conducted with industry experts and solar developers, we determined three key items developers consider when selecting a technology: technological maturity, solar resource at the location of the proposed facility, and cost of installation.

1. Technology maturity: The level of technological maturity was brought up as a key consideration. The relatively long operational history associated with parabolic trough technology was mentioned by one solar developer as the primary reason why their company has chosen CSP technology over all others.[28] Starting with the SEGS I demonstration project back in 1984 through the 1990s with SEGS II through IX, parabolic trough technology has been generating electricity in the California desert for over 25 years. In contrast, while the original concept of the Stirling engine was conceived in the 1800s, this technology has only been applied to solar power production since Stirling Energy Systems, a Scottsdale, Arizona-based systems and integration management company, began serious development in 1996. Additionally, to date, only a 1.5 MW demonstration Stirling Engine facility has been installed. Similarly, photovoltaic technology has experienced only marginal penetration into the utility-scale power generation market, despite being used for various power generation applications since the 1960s, primarily because solar cell manufacturing costs have been too high. However, with increased utility rates and bolstered manufacturing capability, the photovoltaic industry has experienced tremendous growth over the past 15 years[29], which also provides an

indication why roughly 40 percent of the applications submitted to the BLM for review use photovoltaic technology.

2. Solar resource: The solar resource at a given location has a direct impact on the power generating capability of any solar technology system. As discussed earlier, the California desert hosts some of the best solar resource in the world; however, it is not evenly distributed across all regions (Map 3.1). Even within the broader context of the desert region, a 10 percent change in solar resource can occur within a few miles of two different locations.[30] Therefore, in order to produce the same amount of electricity, a 10 percent decline in solar resource translates to a 10 percent increase in facility size, which can lead to cost and other impact implications.



Map 3.1 United States Solar Radiation Resource Map. Source: U.S. Department of Energy.

3. Cost of installation: And finally, the last key consideration for developers is cost. Table 3.1 summarizes installed costs for the various technology options currently available for utility-scale solar facilities. Most technologies included in this list cost the same to install; however, dish/engine systems have a noticeably wider cost range and flat plate PV systems have a minimum cost three times higher most other technologies. Using the 13 Applications for Certification (AFC) that are publicly available for viewing as an indicator of developer preference, two projects each call out the use of power tower, dish/engine and thin film PV technology, while the remaining seven use parabolic trough technology (Table 3.3).

Table 3.3 Installed Cost of Various Utility-Scale Solar Technologies.

Technology Type	# of proposed projects	Installed cost ($/W)
Parabolic Trough	7	3 - 6[31]
Power Tower	2	2 - 5[32]
Dish/Engine	2	2 - 50[33]
Flat plate PV	0	6 - 10[34]
Thin Film PV	2	3 - 5[35]

One factor that is no longer much of a consideration for developers is cooling system type. In September of 2009, the California Energy Commission passed down guidance restricting the use of "wet" cooled systems and mandating the use of "dry" cooled systems for new power generation facilities built in California. However, because applications were submitted prior to the publication of the CEC report, some projects still include plans for the installation of a "wet" cooled system. Therefore, a brief discussion of the tradeoffs related to various cooling system types is warranted. The CEC commissioned an external consultant to research economic, environmental and other tradeoffs. Some of the key findings are summarized in the Table 3.4.

Table 3.4 Tradeoffs of Various Cooling System Technologies.[36]

Tradeoff	"Wet"	"Dry"	Hybrid - Plume abating	Hybrid - Water conserving
Water Consumption	600 to 900 Gal/MWh	~5 percent of "Wet"	Equal to "Wet"	20 to 80 percent of "Wet"
Capital Cost	BASE	1.5x to 3x Base	1.1x to 1.5x Base	3x to 5x Base
Performance Penalty	BASE	5 to 20 percent capacity loss	Equal to Base	Highly variable

CITATIONS

Chapter 3

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