Water Requirements for Utility-Scale Concentrating Solar Power Facilities: Are We Robbing Peter to Pay Paul?

L. William Staudenmaier

For most Americans, electricity affects every aspect of daily life. Electricity helps us work (computers), communicate (cell phones, Internet-based social media), travel (subways, electric rail), cook and store food (stoves, refrigerators, and other electric appliances), and be comfortable in our homes (heating and air conditioning). Electricity is crucial to the functioning of our offices, factories, schools, hospitals, government buildings, and a wide variety of public places. In short, both we as individuals and our economy depend on reliable access to abundant supplies of electricity. Unfortunately, our dependence on electricity comes at a considerable price. We consume vast amounts of natural resources—including water—as we generate, deliver, and use electricity.

A significant majority of the electricity we use is generated by burning fossil fuels. In 2009, for example, nearly 45 percent of the electricity consumed in the United States was generated at coal-fired power plants, while more than 20 percent was generated with natural gas, and an additional 1 percent at oil-fired generators. *See* U.S. Energy Information Administration, Electric Power Annual, 2009: Year in Review, *available at* eia.doe.gov/cneaf/electricity/epa/epa_sum.html. This reliance on fossil fuels has led to increasing concerns about the effects of carbon emissions on our global climate. While climate change is a complicated issue far beyond the scope of this article, one result of these concerns has been that many states have adopted renewable portfolio standards (RPS) to require expanded use of renewable energy by electric utilities. These standards generally require that a set percentage of a utility's electric production come from renewable sources. Although the specific requirements vary widely from state to state, the U.S. Department of Energy (DOE) reports that twenty-four states plus the District of Columbia have some form of mandatory RPS. *See* DOE, Energy Efficiency and Renewable Energy (EERE), States with Renewable Portfolio Standards, *available at* http://apps1.eere.energy.gov/states/maps/renewable_portfolio_states.cfm. Another five states have nonbinding goals that encourage electric utilities to increase their renewable portfolios. Together, these states account for more than half of the electricity consumed in the United States. One of the most ambitious standards is found in California, which has imposed a mandate that 33 percent of total electric generation come from renewable sources by 2030. This will require utilities in California to more than double their current percentage of renewable power, which averages 15 percent among the large utilities in the state.

Mr. Staudenmaier is a partner with Snell & Wilmer in Phoenix, Arizona. He may be reached at wstaudenmaier@swlaw.com.

Most RPS programs allow a wide variety of technologies to satisfy the applicable requirements. For example, solar, wind, geothermal, biomass, and other technologies are eligible in most states. Utility-scale examples of each of these technologies can be found in the current portfolios of many utilities, and all can be expected to grow as utilities strive to meet increasing RPS requirements. As the Electric Power Research Institute (EPRI) stated in a 2008 report on solar power technologies, "a broad portfolio of cost-competitive [electric] supply technologies will be needed to satisfy the world's rising demands for energy while meeting climate policy and other societal objectives." EPRI, New Mexico Central Station Solar Power: Summary Report, (Apr. 2008) (EPRI Report), *available at* www.epri.com/seig.

Of course, utility regulators also emphasize energy efficiency initiatives, sometimes referred to as the least expensive "new" power source available. Such programs, however, can only do so much. If utilities are to meet the RPS standards in their respective states, they will need to rapidly expand their renewable portfolios in the next few years.

Each type of renewable technology has its own advantages and disadvantages that should be considered as utilities expand their portfolios. For example, wind power has the advantage of not requiring any fuel or water inputs to generate electricity. Instead, electricity is produced when wind blows across fan blades, which turn a turbine, generating electricity. Of course, wind turbines only generate electricity when the wind blows. Even the most productive wind power sites have variable wind speeds, including times when the wind does not blow at all. Because wind turbines only produce electricity in direct response to local wind conditions, the amount of electricity generated by any given turbine can vary significantly day by day, hour by hour, and even minute by minute. Nevertheless, wind power is an important and growing part of the renewable portfolio for many utilities.

Similarly, solar power is an increasingly important renewable resource for many utilities. Like wind power, solar power does not require a fuel source to generate electricity. Instead, it relies on energy from the sun. Although electricity can be generated by solar power throughout the United States, it is a particularly important resource in the Southwest, where large expanses of desert provide some of the most suitable locations for utility-scale solar electric generating facilities anywhere in the world. As with wind power, however, solar power can present a number of challenges that should be considered as utilities expand their renewable portfolios.

There are two distinct types of solar power technology in

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common use today: (1) photovoltaic power, in which solar energy is converted directly into electrical energy by means of semiconductor materials arrayed in solar panels, and (2) concentrating solar power (CSP), in which solar energy is concentrated through the use of mirrors, often to heat a fluid and generate steam to turn a turbine, much like a traditional fossil fuel-based power plant—but without the carbon emissions.

Photovoltaic power is frequently used in "distributed" applications in which solar panels are placed on residential, commercial, and industrial rooftops or other locations where a utility's retail customers can obtain electricity directly from the panels. This ability to distribute solar panels at locations where electricity is consumed has resulted in widespread and growing use of photovoltaic technology throughout the United States. Increasingly, photovoltaic power also is being developed in utility-scale, "central station" power plants where thousands of photovoltaic panels are combined in large arrays and the power is fed into regional transmission grids. Unless constructed with a battery storage system or conjunctively operated with another power supply (often a natural gas-fired combustion turbine), these central station photovoltaic facilities are subject to considerable variability in electric output because photovoltaic panels only generate electricity when exposed to direct sunlight. This variability can be similar to that exhibited by wind turbines. Just as the wind does not always blow at a consistent speed, the amount of direct sunlight available to a given solar panel can change from minute to minute as clouds pass overhead. EPRI's 2008 study of solar power technologies noted the "limited operating flexibility and variable power output" from a number of existing central-station photovoltaic power facilities. EPRI Report at 6-1. This variability was attributed to "intermittent cloudiness." *Id.* Importantly, these existing facilities are located in the Southwest, where sunny days are the norm. Variable power output may be an even greater concern in parts of the United States that experience more frequent overcast days. These concerns have not prevented growing use of central-station photovoltaic technology, but they do affect the ability of utilities to rely on such facilities to consistently supply electricity throughout peak power demand periods.

Concentrating Solar Power Projects

In contrast to photovoltaic solar power, CSP technology is almost always developed in central station facilities, with generating capacities ranging from several megawatts to several hundred megawatts. These larger facilities, if constructed with a heat storage mechanism (typically molten salt, which can hold excess heat captured during peak periods of solar intensity until it is needed later in the day or evening), can better match the peak load demand for electricity, which usually continues several hours past the solar energy peak. This ability to generate a consistent level of electricity throughout the peak demand period has prompted numerous proposals for new utility-scale CSP facilities in the desert Southwest. In Arizona alone, more than forty such facilities have been proposed for federal and state public lands, and still more have been proposed for development on private lands within the state. Similar proposals have been made to construct substantial numbers of CSP facilities in California, Nevada, New Mexico, and other states. *See* DOE-EERE/BLM, Solar Energy Development Programmatic Environmental Impact Statement (Dec. 2010), Executive Summary at ES-1, *available at* http://solareis.anl.gov/.

In a recent report to Congress, DOE estimated that CSP facilities located on just 1.4 percent of the land base in the desert regions of southern California, southern Nevada, southwestern Arizona, and western New Mexico could theoretically generate more electric power than is currently consumed in the entire United States. DOE, Report to Congress, Concentrating Solar Power Commercial Application Study: Reducing Water Consumption of Concentrating Solar Power Electricity Generation, (undated) (Report to Congress) at 6; *available at* www1.eere.energy.gov/solar/pdfs/csp_water_study.pdf. Unfortunately, as the DOE Report to Congress also notes, "[w]ater consumption is an issue with concentrating solar power plants because they are most cost effective in locations where the sun is most intense, which in turn often corresponds to places like the Mohave Desert where there is little water." *Id.* Indeed, if not carefully addressed by the proponents of new CSP power plants, concerns about water demand at such facilities could prove to be the Achilles heel of this technology.

As noted above, CSP technology often uses heat captured from sunlight to generate steam, which then turns a turbine to generate electricity. Although there are CSP technologies that do not generate steam, the 2008 EPRI Report noted that most of these technologies are still being developed and are not yet ready for large-scale commercial applications or, like photovoltaic technology, they have no inherent heat storage capabilities. As such, "intermittent cloudiness" can result in rapid changes in power output, thereby affecting the ability of utilities to use these technologies to consistently meet peak power demands. EPRI Report at 3–4.

Because of these concerns, DOE has pledged up to $62 million over the next five years to "research, develop, and demonstrate Concentrating Solar Power (CSP) systems capable of providing low-cost electrical power." DOE Press Release, *Secretary Chu Announces up to $62 Million for Concentrating Solar Power Research and Development* (May 7, 2010), *available at* www.energy.gov/8958.htm. Most of this funding is focused on advancing new technologies to "improve component and system designs to extend operation to an average of about 18 hours per day, a level of production that would make it possible to displace traditional coal-burning power plants." *Id.* The $62 million pledged by DOE is a very modest sum compared to total expenditures on renewable—not to mention conventional—energy development. With increasing pressure on the federal budget, however, additional funding for development of alternative CSP technologies will likely need to come from the private sector. Such investments may pay considerable dividends in the form of reduced water consumption and other environmental benefits, but the extent to which additional funds will be committed by the private sector remains to be seen.

In contrast to these alternative CSP technologies, EPRI found that "conventional," steam-generating CSP "is a mature commercial technology that has generated electricity reliably for over two decades," and that financing for such facilities "is comparable to other mature, commercial generation technologies." EPRI Report at 3–5. Furthermore, because conventional CSP facilities are typically constructed with heat storage capabilities, they provide a "buffer against rapid transients that might otherwise cause sharp drops and rises in power output," allowing "system operators to arrange for alternative generation sources during cloud coverage." *Id.* Because of these benefits, conventional facilities represent the majority of the current proposals to develop CSP power plants in the desert Southwest.

The Need for Water

Like all steam-based power plants, conventional CSP facilities must cool the steam to condense it back to liquid form to complete the "steam cycle." This reduction in temperature can be accomplished in several ways. The most common method is to use water in a traditional "wet" cooling system. In such a system, after the steam turns the turbine, it is routed through a wet condenser, where heat is transferred to cooling water. This cooling water, now carrying excess heat removed from the steam, is directed to a cooling tower where the heat is released to the atmosphere through evaporation. This method of condensing steam is very efficient, but it also consumes a lot of water. In fact, for a variety of technical reasons, conventional wet-cooled CSP facilities are estimated to use considerably more water per megawatt hour of electricity generated than most fossil fuel power plants.

The use of water in conventional CSP facilities has become an issue of increasing scrutiny.

A potential alternative to wet cooling is dry cooling. With dry cooling, steam is condensed to liquid form by routing it through an air cooled condenser over which large fans blow ambient air to dissipate heat. In moderate temperatures, this technology can be effective, although even in the best of circumstances, it is a less efficient method of condensing steam than wet-cooling systems. Dry cooling, however, becomes increasingly less efficient at higher temperatures. As DOE notes, "[d]ry cooling systems are more expensive and result in lower plant thermal efficiency, especially in hot climates and on hot days—typically when and where peak power is most in need." DOE Report to Congress at 13. Specifically, DOE compared the performance of wet- and dry-cooled systems in the Mohave Desert and found that "the performance of the air-cooled system dropped off significantly at ambient air temperatures above 100°F." *Id.* at 14. Because summer afternoon temperatures in the deserts of southern Arizona, California, and Nevada frequently exceed 100 degrees, the viability of dry-cooling systems in these locations is questionable. The times during which a dry-cooling system would experience the most significant decreases in power production are exactly those times when utilities must meet peak summer afternoon power demands.

Yet another alternative to traditional wet cooling is a hybrid system that provides dry cooling during moderate temperatures but allows wet cooling during peak summer daytime temperatures when the efficiency of dry cooling significantly deteriorates. These systems are typically constructed with side-by-side wet- and dry-cooling structures. When wet cooling is required, steam is condensed on the wet side of the system. At other times it is condensed using the dry side. These hybrid systems can help alleviate the significant efficiency losses encountered in dry-cooling systems when temperatures exceed 100°F, while still resulting in considerable water savings. As a result, hybrid systems may prove to be an attractive alternative to either a wet-cooled or a dry-cooled system. Hybrid systems, however, can be considerably more expensive than either wet- or dry-cooled systems because they require construction of parallel, and partially redundant, cooling equipment.

These concerns are not merely academic, nor are they just a simple matter of economic analysis of competing power systems. Rather, the use of water in conventional CSP facilities has become an issue of increasing scrutiny by state utility regulators, public land managers, environmental organizations, and even members of Congress. For example, utility regulators in Arizona and California have considered imposing water use constraints on future CSP facilities in those states. In Nevada, the National Park Service raised concerns about the effects of using limited groundwater supplies in that state to meet cooling water requirements of a proposed CSP facility. Similar concerns have been raised by the Environmental Protection Agency in comments submitted to the Bureau of Land Management (BLM) concerning a conventional CSP facility proposed for BLM land near Phoenix, Arizona.

Most notably, the office of Sen. Jon Kyl (R-AZ), an influential expert on western water issues, produced a white paper exploring the dilemma identified by the Department of Energy—that the locations most desirable for production of solar power are very likely to also be some of the most water-limited regions of our country. Office of Sen. Jon Kyl, *Water Policy Considerations—Deploying Solar Power in the State of Arizona: A Brief Overview of the Solar-Water Nexus* (May 2010) (the Kyl Report). The Kyl Report takes a very critical view of conventional, wet-cooled CSP facilities, stating that the purpose of the paper "is to raise awareness within Arizona about the harmful impact solar energy production has on the state's limited water supply." *Id.* at 3. The Kyl Report analyzes the amount of water required to operate a wet-cooled CSP facility and compares the findings of previously published studies regarding water availability and solar power potential. Based on these studies, the Kyl Report states that "Arizona is one of the most susceptible states to water supply constraints *and* at the same time has one of the highest capacities for CSP. In other words, one of the most targeted areas for solar development is also one of the most water-constrained areas in the United States." *Id.* at 11 (emphasis in original).

The Kyl Report also raises concerns regarding the potential that CSP facilities will be constructed in Arizona only to have the resulting power exported to other states that have imposed ambitious RPS requirements. Interestingly, these concerns are focused on the effect of such facilities on Arizona's water supply. As the Kyl Report states,

> [p]lacing additional demands on Arizona's water supply in order to export 'renewable energy' to other states that have

> greater energy demands is unsustainable. Arizona should not become a solar energy farm for the rest of the country, especially when its water supply is limited and is currently in the midst of a long-term drought.

Id. at 18.

Although this position raises significant questions concerning interstate commerce in a part of the country with a fully integrated regional power grid, concerns about water supply constraints are genuine and significant and must be thoughtfully addressed by proponents of conventional CSP facilities. Proponents who fail to do so run the risk of seeing their projects blocked by state regulators, public land and water resource managers, and concerned members of the public.

As proposed solutions to this dilemma, the Kyl Report discusses the possibility of using dry cooling or hybrid cooling systems as alternatives to wet cooling and recommends that if future CSP power plants in Arizona are wet cooled that they be required to use "degraded water . . . such as city wastewater." *Id.* at 20. The potential merits and limitations of dry cooling and hybrid cooling have been discussed above. The final recommendation, that "degraded water" be used in wet-cooled CSP facilities, is a concept that makes considerable sense in the desert Southwest. Treated wastewater (effluent) is already used on a large scale in Arizona as a cooling water source for the Palo Verde Nuclear Generating Station, located 55 miles west of Phoenix. Effluent is an important water supply that grows as population increases (as does the demand for electricity), yet effluent is not available for potable uses. As a result, using effluent as a cooling water source, whether for conventional CSP facilities or any other type of steam electric generating facility, can be an excellent way to address two competing concerns, the need to meet growing demands for electricity in an environmentally responsible manner while not overtaxing our limited and precious freshwater resources. As the Kyl Report notes, another approach would be to use degraded groundwater (typically high concentrations of total dissolved solids), which can be found in many areas of southwestern states. Because these water sources are not readily available for potable uses, they may be a viable supply for conventional CSP facilities in some locations.

Although the views expressed in the Kyl Report were focused on circumstances in Arizona, similar concerns have been voiced regarding water demands for conventional CSP facilities in California, Nevada, and New Mexico. In all of these states, concerns about water use in renewable energy facilities and limited availability of additional water supplies will prompt greater regulatory scrutiny of such facilities in the future. Even the 2008 EPRI Report, which was simply an analysis of alternative solar technologies and was not intended to advocate a particular policy-based outcome, noted that use of dry- or hybrid-cooling technology could "greatly increase the range of public acceptance." EPRI REPORT at 7–3. Improved public acceptance, however, must be balanced with the need to reliably produce power when and where it is needed. If a dry-cooled facility becomes severely inefficient during the hottest days of the summer, it will be of limited value in meeting peak electricity demand. This could, in turn, lead to continued use of traditional fossil-fueled power plants (most of which are wet-cooled facilities) to meet those peak demands.

Interestingly, concerns regarding the amount (and quality) of water used to generate electricity are neither new, nor are they solely focused on water requirements for renewable energy facilities. As long ago as 1975, the California State Water Resources Control Board adopted a policy raising concerns about the use of freshwater sources in California for power plant cooling purposes. *See* California State Water Resources Control Board, Resolution No. 75-58, *Water Quality Control Policy on the Use and Disposal of Inland Waters Used for Powerplant Cooling* (June 19, 1975). In this policy, the Board noted the possibility of widespread water shortages in future years and stated that it would approve the use of freshwater resources for power plant cooling "only when it is demonstrated that the use of other water supply sources or other methods of cooling would be environmentally undesirable or economically unsound." *Id.* at 4. The Board made this policy applicable to fossil fuel, nuclear, and solar power facilities that require water for cooling. The policy states that proposals for future power plants "should include an analysis of the cost and water use associated with the use of alternative cooling facilities employing dry, or wet/dry modes of operation." *Id.* at 5. Finally, the policy expressly "encourages the use of wastewater for power plant cooling where it is appropriate" and notes the desirability of using brackish (i.e., highly saline) waters as another preferred alternative to freshwater resources.

Recommended use of "degraded water" in wet-cooled CSP facilities makes sense in the Southwest.

Concerns regarding wise use of limited water resources in the southwestern United States have only grown in the thirty-five years since the California State Water Resources Control Board issued its policy on use of water supplies for power plant cooling. Indeed, water supply concerns have now spread across the United States to locations that were once thought to have abundant water. For example, water disputes affecting power plants have occurred in the Carolinas, Georgia, Alabama, and Florida in recent years.

As our nation moves forward with plans to significantly expand renewable energy resources, we must be mindful of the potential adverse effects on our water resources. This dilemma should prompt careful consideration of the best approach to developing CSP facilities. In all likelihood, one size will not fit all. For example, a dry-cooled CSP facility may be viable in a location with moderate summer temperatures, while a hybrid or even a wet-cooled facility may be the best choice in the hottest parts of the desert Southwest. Planning a conventional CSP facility should involve careful evaluation of alternative cooling technologies such as dry or hybrid cooling. If engineering or economic considerations make these options problematic, alternative water supplies (such as treated wastewater or brackish groundwater) should be evaluated when planning a wet-cooled CSP facility.