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Water Issues of Concentrating Solar Power (CSP) Electricity in the U.S. Southwest

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Summary

As the 111th Congress considers energy and climate legislation, the land and water impacts of renewable technologies are receiving greater attention. The cumulative impact of installing numerous thermoelectric power plants on the water resources of the Southwest, a region with existing water constraints, raises policy questions.

Solar Abundance and Water Constraints Converge. Many Southwest counties are premium locations for siting solar electricity facilities, but have constrained water supplies. One policy question for local, state, and federal decision-makers is whether and how to promote renewable electricity development in the face of competing water demands. A principal renewable energy technology being considered for the Southwest is concentrating solar power (CSP), which uses ground-based arrays of mirrors to concentrate thermal solar energy and convert it into electricity. The steam turbines at CSP facilities are generally cooled using water, in a process known as wet cooling. The potential cumulative impact of CSP in a region with freshwater constraints has raised questions about whether, and how, to invest in large-scale deployment of CSP. Much uncertainty about the water use impacts of CSP remains because its water demand is highly dependent on the location and type of CSP facilities constructed (e.g., whether thermal storage is included and whether wet cooling is used), and because the data for these evolving technologies are preliminary.

Water Consumption and Electricity Generation Tradeoffs. In arid and semi-arid regions like the Southwest or in other areas with intense water demand, water supply is an issue for locating any thermoelectric power plant, not only CSP. The trend is toward more freshwater-efficient cooling technologies for CSP and other thermoelectric generation. Why is there concern specifically about the CSP water footprint? CSP facilities using wet cooling can consume more water per unit of electricity generated than traditional fossil fuel facilities with wet cooling. Options exist for reducing the freshwater consumed by CSP and other thermoelectric facilities. Available freshwater-efficient cooling options, however, often reduce the quantity of electricity produced and increase electricity production costs, and generally do not eliminate water resource impacts.

The quantity of electricity produced at these facilities, the water intensity per unit of electricity generated, and the local and regional constraints on freshwater will shape the cumulative effect of CSP deployment on southwestern water resources and the long-term sustainability of CSP as a renewable energy technology. Water resource constraints may prompt adoption of more freshwater-efficient technologies or decisions not to site CSP facilities in certain locations.

Next Steps. Water constraints do not necessarily preclude CSP in the Southwest, given the alternatives available to reduce the freshwater use at CSP facilities. Moreover, water impacts are one of many factors (e.g., cost, climate and air pollution emissions, land and ocean impacts, wildlife and the environmental impacts) to be weighed when judging the tradeoffs between different energy options. States are responsible for most water planning, management, and allocation decisions and electricity siting decisions. Whether and how the federal government should promote water conservation, efficiency, markets, and regional- and state-level planning and collaboration is a matter of debate. At the same time, federal policies (e.g., energy, agriculture, and tax policy) can affect water-related investments and water use, and operations of federal facilities can affect the water available for allocation.

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Concentrating Solar Power and Its Water Use

Large-scale deployment of concentrating solar power (CSP), a renewable energy technology for generating electricity, has the potential to affect the availability of water resources in the Southwest for other uses. Because the water demand of CSP is highly dependent on the type of CSP facilities constructed (e.g., whether thermal storage is included and whether wet cooling is used) and their locations, and because the data for these evolving technologies are preliminary, there remains much uncertainty about the impacts of CSP on Southwest water use. Water resource constraints are likely to prompt adoption of more freshwater-efficient technologies, or decisions not to site CSP facilities in certain locations. However, water constraints do not necessarily preclude CSP in the Southwest, given the ability to reduce the freshwater use at CSP facilities. This report presents a brief primer on CSP, then discusses the potential water implications of CSP deployment in the Southwest.

Introduction to CSP and Its Policy Context

CSP comprises a set of technologies that convert thermal solar energy into electricity. The quantity of electricity produced at these facilities, the water intensity per unit of electricity generated, and the local and regional constraints on freshwater will shape the cumulative effect of CSP deployment on southwestern water resources, and the long-term sustainability of CSP as a renewable energy technology.

As the 111th Congress considers energy and climate legislation, and as individual states take actions such as adopting renewable energy portfolios and identifying geographic regions suitable for renewable energy development, the implications of large-scale adoption of renewable technologies are receiving greater attention. How large-scale expansion of solar generation in the Southwest may affect the people, economy, land, protected species, and water resources of the region are being analyzed in order to compare the local, regional, and national advantages and disadvantages of CSP compared to other electricity options. Site-specific and cumulative water resource implications are among many factors (e.g., cost, climate and air pollution emissions, land and ocean impacts, wildlife and the environment impacts) to be weighed when judging the tradeoffs between different energy options.

CSP Technologies

CSP—or solar thermal power, as it is also known—typically employs large arrays of ground-based mirrors to concentrate sunlight onto a heat transfer medium (e.g., oil, salt, or water), which is heated above 212°F (100°C) to roughly 662°F (350°C), depending on the medium. The heat is used to generate steam via a heat exchanger to spin a steam turbine. Alternatively, steam can be generated directly by the mirror arrays. Photovoltaic (PV) solar is a separate class of solar technology that uses panels of solar cells to convert sunlight directly into electricity. Operation of CSP and PV facilities to generate electricity does not directly release greenhouse gases. There remains significant uncertainty about the future rate and level of CSP deployment.

In some CSP installations, sunlight is concentrated from the mirror arrays onto a single, central location atop a tall *solar tower* where the heat typically melts salt or boils water. In other CSP installations, solar parabolic-mirror troughs, also known as *solar troughs*, focus sunlight on miles of piping running through a field of mirrors, heating the heat transfer fluid (usually oil).

Pressurized steam, produced by the heat transfer medium, then drives a turbine-generator producing electricity. Other less common CSP technologies exist; this report focuses on solar trough and solar tower CSP technologies.[1]

CSP currently is better suited than PV installations for larger facilities,[2] and the steam-cycle used in CSP is more familiar to utility engineers. Electricity from a large CSP plant is estimated to cost $0.10 per kilowatt-hour (kWh) over a facility's operating life; electricity from a large PV facility is estimated at $0.26/kWh given current technologies.[3] In terms of cost, both PV and CSP facilities at the scale now being developed (generally between 50 megawatts (MW) and 1,200 MW) are at an early stage in their commercial adoption and use; these early facilities are anticipated to produce electricity at more than twice the cost of conventional coal plants. CSP generation costs are expected to decrease as more solar plants are installed and technologies and operations improve.

As of March 2009, 11 large solar trough facilities were operating in the United States (1 in Arizona, 1 in Nevada, and 9 in California), with a total capacity of 339 MW.[4] An additional 16 large-scale solar trough and solar tower plants are planned. The 15 in the West ─ 1 in Arizona, 2 in Nevada, and 12 in California ─ have planned capacities totaling 4.0 gigawatts (GW). The one in Florida is planned as a 75 MW facility.

Adding heat storage, such as molten salt storage, can improve the economics of CSP operation because it allows the heat retained in storage to produce electricity into the night hours.[5] The availability of thermal storage technologies gives CSP an additional advantage over PV. The CSP facility currently operating in Arizona has plans to add thermal storage. The first large-scale CSP plant with thermal storage began operations in Granada, Spain, in November 2008; the facility is a 50 MW plant with seven hours of thermal storage.

CSP Water Use and Cooling Technologies

CSP technologies generate power via the same steam cycle as coal or nuclear power plants; the main difference is the fuel used to turn water into steam. There are two major water processes in a steam turbine system—the steam cycle and the cooling process. Most of the water is consumed

[1] For example, dish Stirling, also known as a dish engine, is a less common type of CSP not analyzed in this report. Dish Stirling is distinguished from solar trough CSP because it uses a Stirling engine rather than a steam turbine. A dish Stirling system uses the mirrors to concentrate sunlight to heat a gas chamber connected to a piston and drive shaft. The drive shaft powers an electricity generator. Because of the high operating temperature and high efficiency of the Stirling motor, air cooling can be used with little compromise of overall electricity generation efficiency. This significantly reduces the water used to generate electricity compared to other CSP technologies. There are four dish Stirling facilities proposed for installation in California (Solar Energy Industries Association, "Major Solar Projects: Operational and Under Development 5/27/09," available at http://www.seia.org/galleries/pdf/Major%20Solar%20Projects.pdf).

[2] U. Wang, "Solar Thermal vs. PV: Which Tech will Utilities Favor," greentechmedia (Feb. 24, 2009), available at http://www.greentechmedia.com/articles/solar-thermal-vs-pv-which-tech-will-utilities-favor-5774.html. Although operating U.S. PV facilities have capacities less than 15 MW, larger PV facilities with capacities between 250 and 550 MW are now under development.

[3] See Table 4 in CRS Report RL34746, *Power Plants: Characteristics and Costs*, by (name redacted).

[4] Data in this paragraph are from Solar Energy Industries Association, "Major Solar Projects: Operational and Under Development 5/27/09," available at http://www.seia.org/galleries/pdf/Major%20Solar%20Projects.pdf.

[5] Department of Energy, Office of Energy Efficiency and Renewable Energy's Concentrated Solar Power Program, Thermal Storage website, available at http://www1.eere.energy.gov/solar/thermal_storage.html.

during cooling,[6] and the choice of cooling technology largely determines how much water is actually consumed at a facility. Fossil and nuclear power plants use the same wet-cooling technologies as those for CSP.

Water is used to produce steam to turn the steam turbines; this water is recycled for the generation of steam in the "closed-loop" steam cycle. Theoretically, water is not lost in the steam production cycle (though real-world imperfections necessitate some "make-up" water to compensate for leaks in the system). Steam is cooled in a condenser and condensed back to a liquid water state to be reused.

The condenser itself is then cooled. For *wet cooling* of the condenser, the most common technology is to use a separate circuit of water to remove the heat from the condenser; this water then flows to an evaporative cooling tower that dissipates the collected heat energy to the environment. Most of this cooling water is lost as clouds of water vapor to the atmosphere as the condenser water contacts the air and the cooling tower. Alternatively, wet cooling can also occur by sending the condensed steam directly to the cooling tower. The 11 large-scale CSP facilities operating in the United States all use wet cooling.

In areas where water supplies are constrained, *dry cooling* technologies may be used, which blow air over extensive networks of steam pipes designed with convective cooling fins to dissipate the heat energy over their surface area. No water is used or consumed in dry cooling. Air, however, has a much lower capacity to carry heat than water; therefore, dry cooling generally is less efficient than wet cooling in removing heat.[7] Often, massive cooling fans are used to remove the heat from the pipe array in dry cooling. These fans consume a portion of the electricity generated by the power plant. Although dry cooling reduces water use, its consumption of energy for cooling fans and reduction of thermal efficiency of the steam turbines, especially on the hottest days of the year, when summer-peaking utilities most need power, is a significant factor impeding its adoption. It may be possible to offset the effect of dry cooling on net electricity generation by using bigger solar collecting fields or perhaps PV systems to run cooling fans. Where efficiency is a concern and water is constrained, a hybrid combination of wet and dry cooling technologies may be used. (See "Reducing the CSP Water Footprint," below, for more information on hybrid cooling.) CRS was not able to identify any operating large-scale CSP facility in the United States or the world that uses dry cooling, but the technology is being considered as new CSP proposals are being developed in water-constrained areas, such as Southern California counties.

Technological Next Steps

Further research on materials and the thermal properties of the heat transfer medium in solar installations may allow the medium to reach higher temperatures, producing hotter steam for the turbines and greater electricity output. However, steam turbine operating characteristics are constrained by the materials used to manufacture the turbines. These materials will then determine how well the turbine is able to accommodate high pressures. Another alternative to

[6] Presentation on "Water Use & Conservation in the Utility Industry" by K. Zammit of Electric Power Research Institute, on June 17, 2008, available at http://robinson.gsu.edu/resources/files/ethics/summer_seminar_series/kent_zammit.pdf.

[7] California Energy Commission, "Comparison of Alternate Cooling Technologies for California Power Plans: Economic, Environmental and Other Tradeoffs, Consultant Report," Feb. 2002, available at http://www.swrcb.ca.gov/santaana/water_issues/programs/aes/docs/pier_comparison_of_cooling_technologies.pdf.

increase output would be to add a combustion turbine to the existing solar cycle. If higher-temperature steam can be produced, then combustion turbines operating at lower pressures can be used to augment the solar steam turbines, resulting in more efficient energy output. Ongoing research at the U.S. Department of Energy's National Renewable Energy Lab (NREL) has shown that an integrated solar combined cycle plant would have efficiencies higher than those of a solar-only plant, and potentially higher than those in a fossil-fuel combined-cycle plant. It also has costs 25% to 75% lower than those of a solar-only plant, and offers the lowest cost of solar electric energy among hybrid options.[8]

Convergence of Solar Abundance and Water Constraints

In arid and semi-arid regions like the Southwest, or other areas with intense water demand, water supply is an issue for locating any thermoelectric power plant, not only CSP. The cumulative impact of installing multiple thermoelectric power plants in a region with existing water constraints raises numerous policy questions. As previously noted, there is significant uncertainty about the future rate and location of CSP deployment; this uncertainty significantly restricts the ability to evaluate the extent and location of potential water resource implications of CSP deployment. Additional data and analysis on where CSP may deploy and how it may affect local water availability would benefit federal, state, and local decision-makers when evaluating the potential consequences of general policies and individual permitting and siting decisions. The analysis presented in this report is based on available projections for CSP deployment at the county level.

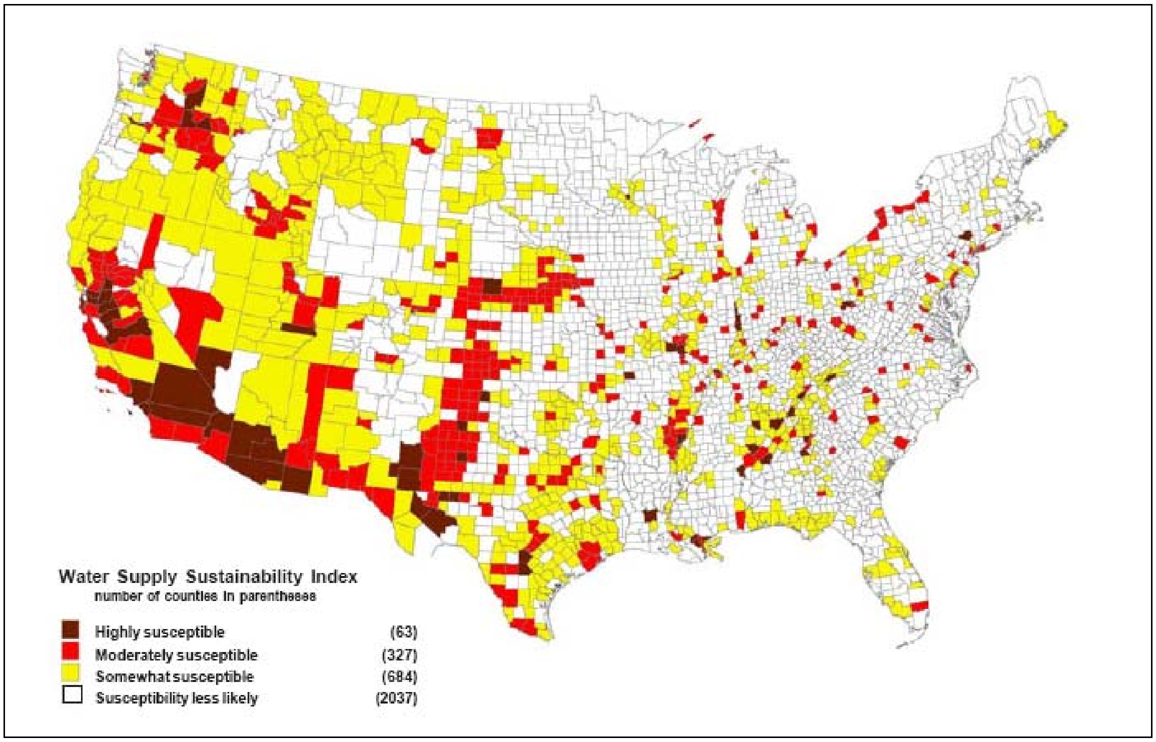
Mapping Water Constraints and CSP Deployment

The Electric Power Research Institute (EPRI) developed an index of the susceptibility of U.S. counties to water supply constraints. The index was derived by combining information on the extent of development of available renewable water supply, groundwater use, endangered species, drought susceptibility, estimated growth in water use, and summer deficits in water supply. EPRI produced **Figure 1**, which shows the susceptibility to constrained water supplies.

Comparing the water constraint index to NREL's projection of CSP deployment by 2050, in **Figure 2,** shows overlap, particularly in Arizona and California. NREL's analysis did not consider water availability as a constraint on CSP deployment. This overlap represents a policy issue for local, state, and federal decision-makers: should the federal government promote electricity generation given local water resource constraints and demands, and if so, how? For example, what kinds of solar technologies are most appropriate for counties susceptible to water supply constraints?

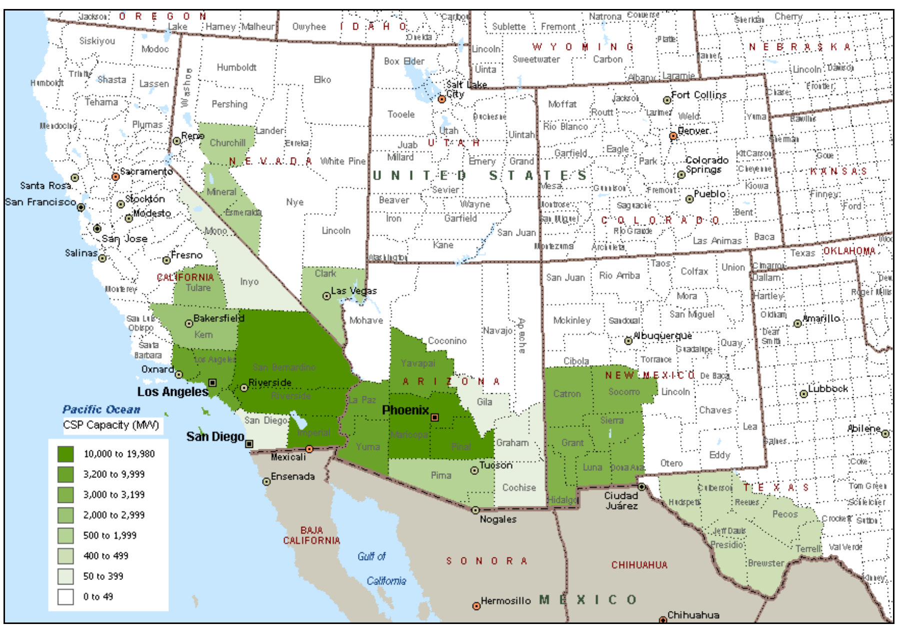
[8] For a schematic description of this technology, see http://www.nrel.gov/csp/troughnet/pdfs/bruce_kelly_isccs.pdf.

Figure 1. EPRI Water Constraint Index



Source: EPRI, *A Survey of Water Use and Sustainability in the United States with a Focus on Power Generation*, Topical Report, Nov. 2003. EPRI's analysis did not include Alaska and Hawaii.

Figure 2. NREL Projected CSP Capacity in 2050

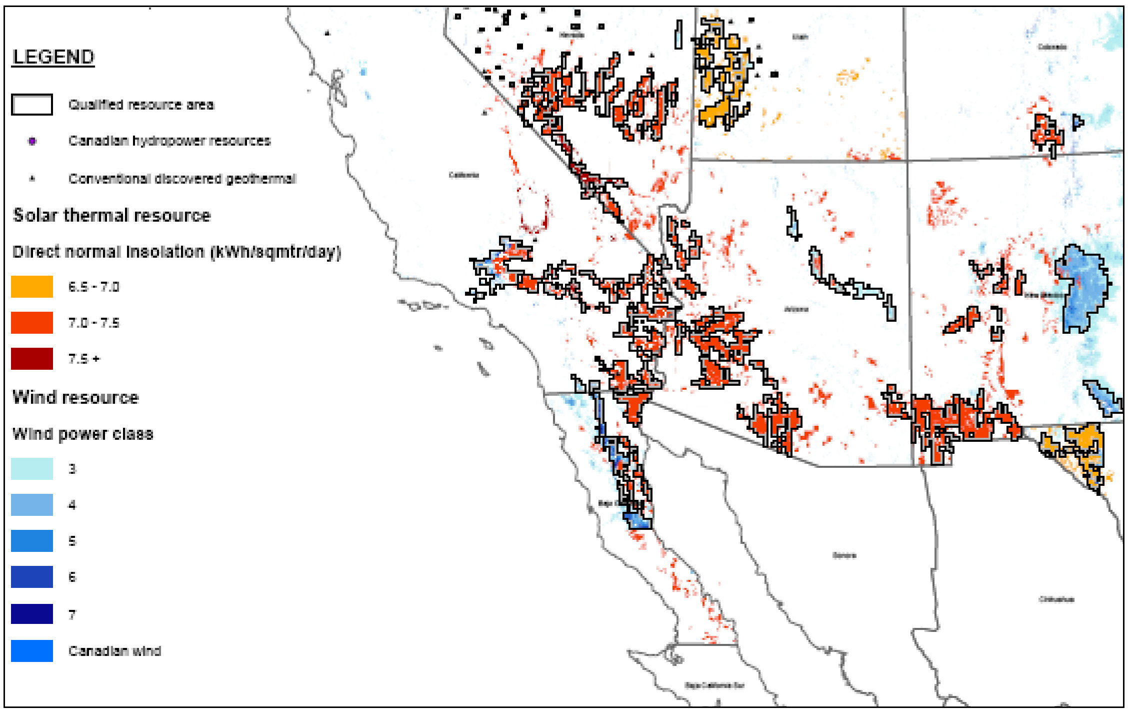


Source: N. Blair, Concentrating Solar Deployment Systems (CSDS) – A New Model for Estimating U.S. Concentrating solar Power Market Potential (undated), available at http://www1.eere.energy.gov/solar/review_meeting/pdfs/p_55_blair_nrel.pdf.

Figure 2 represents one projection of where CSP may be deployed based on federal and state policies, prices, and costs at the time of the analysis.[9] These model inputs are dynamic, and the models are being improved. In particular, when, where, and how much CSP is installed by 2050 and the technologies used are sensitive to state and federal policies. Consequently, NREL plans to release updated projected deployments based on changes in these inputs, as well as proposed changes (e.g., analyses of the impacts of climate change bills on CSP deployment).

The Western Governors' Association (WGA) is producing a map of potential renewable energy zones taking into consideration renewable resources, transmission, and wildlife issues. The WGA analysis focuses on transmission feasibility, while the NREL deployment projections were based on a CSP market analysis. Because of these differences, the initial results of the WGA mapping effort show a different depiction of potential locations for solar facilities (**Figure 3**).[10] For example, **Figure 3** identifies more opportunities for solar deployment in Utah and Colorado.

Figure 3. Portion of WGA Draft Preliminary Qualified Resources Area Map



Source: WGA, *Draft Potential Renewable Energy Zones,* available at http://www.westgov.org/wga/initiatives/wrez/zita/QRA-map-Jan30.pdf.

[9] Since this analysis, NREL has released other projections of CSP deployment. A May 2009 report projected 21 GW deployment by 2030 given existing state and federal laws; P. Sullivan et al., *Comparative Analysis of Three Proposed Federal Renewable Electricity Standards* (NREL, May 2009), available at http://www.nrel.gov/docs/fy09osti/45877.pdf. This NREL report, however, did not provide information on which states and counties are projected as the location for the deployment and for the consumption of the produced electricity. Therefore, CRS chose to use the earlier report in order to provide an illustrative example of how deployment may affect state and local water resources (see **Appendix**).

[10] The WGA renewable energy zone map is being refined to exclude crucial wildlife habitat and corridors and lands significant to sensitive species.

Like the NREL analysis used to develop **Figure 2**, the WGA mapping effort does not consider water availability or water resource impacts when designating the areas for renewable development. Many of the counties with solar development zones in the draft preliminary WGA map are the same counties that EPRI found to be highly and moderately susceptible to water supply constraints (see **Figure 1**). The WGA map also shows potential for CSP deployment in areas somewhat susceptible to water supply constraints (e.g., Utah).

CSP with Wet Cooling and Its Water Footprint

Water Intensity of CSP

As shown in **Figure 2** and **Figure 3**, CSP is likely to be concentrated in the Southwest, while new fossil fuel thermoelectric facilities would be more dispersed across the country. This concentration of CSP in a region of the country with water constraints has raised questions about whether, and how, to invest in large-scale deployment of CSP.

Most electricity generation requires and consumes water (see **Table 1**). Wind is an exception, and PV consumes water only for washing mirrors and surfaces.[11] The water consumed per megawatt-hour (MWh) of electricity produced is referred to as the energy technology's *water intensity*.

Why is there concern specifically about the CSP water footprint? CSP using wet cooling (i.e., solar trough and solar tower) consumes more water per MWh than some other generation technologies, as shown in **Table 1**. The water intensity of electricity from a CSP plant with wet cooling generally is higher than that of fossil fuel facilities with wet cooling. However, its water intensity is less than that of geothermal-produced electricity.

As previously discussed and as shown by comparing the second and third columns in **Table 1**, the majority of water consumption at a CSP facility occurs during the cooling process. The fourth column in **Table 1** depicts the water consumed in producing the fuel source; this water consumption generally does not occur at the same location as generation.

Although CSP cooling technologies are generally the same as those used in traditional thermoelectric facilities, the CSP water footprint is greater due to CSP's lower net steam cycle efficiency. Options exist for reducing the water consumed by thermoelectric facilities, including CSP facilities; however, with current technology, these options reduce the quantity of energy produced and increase the energy production cost.

Capacity Factors

Because water use is a function of electricity produced, a key factor determining the amount of water used at a CSP facility is the amount of electricity to be produced during a period of time. How much electricity a CSP facility will generate in a year depends on the amount of time the facility operates. The utilization of a facility is measured by its *capacity factor*, which is expressed as a percent. This is the ratio of the amount of power generated at a facility to the

[11] The water requirements for PV and dish Stirling are estimated at 5 gal/MWh (NREL, *Fuel from the Sky: Solar Power's Potential for Western Energy Supply*, NREL/SR-550-32160 (July 2002), p. 99, available at http://www.nrel.gov/docs/fy02osti/32160.pdf). Some wind facilities may use water for blade washing.

maximum amount of power the facility could have generated if it operated at continuously at maximum output. *Capacity* is the maximum potential instantaneous power output rate at a facility. A capacity factor allows for electricity estimates to be made using information on a plant's capacity. Notably, many of the goals for solar deployment are being stated in capacity terms, that is, in kilowatts (kW), MW, or GW, not in terms of electricity generated (kilowatt-hours or MWh).

Baseload plants typically have capacity factors of more than 70%, and peaking plants of about 25% or less; cycling plants fall in the middle. For most CSP facilities currently proposed in the Southwest using wet cooling, the capacity factor ranges from 25% for solar troughs without storage to greater than 40% for solar troughs with six hours of thermal storage.[12]

Table 1. Water Intensity of Electricity by Fuel Source and Generation Technology

Generation Technology	Water Consumed in Wet Cooling[a] (gal/MWh)	Other Water Consumed in Generation[b] (gal/MWh)	Water Consumed in Producing Fuel Source (gal/MWh)
Solar Trough	760-920	80[c]	0
Solar Tower	750	80[c]	0
PV	0	5[d]	0
Wind	0	0	0
Fossil Thermal	300-480	30	5-74
Biomass	300-480	30	Highly variable depending on whether biomass is irrigated[e]
Nuclear	400-720[f]	30	45-150
Geothermal	1400	Not available	Not available
Natural Gas Combined Cycle	180	7-10	11
Coal IGCC[g]	200	137-140	5-74
Hydroelectric	Not applicable	0	Highly variable, avg. 4,500 due to evaporation

Source: Unless otherwise noted, data calculated from DOE, *Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water*, Dec. 2006, available at http://www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf,.

Notes:

a. Data is for cooling tower technology.

b. DOE, *Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water*, included some of the other water consumed onsite at the generation facility, but appears not to have captured all of the non-cooling water consumed. Collection and dissemination of data that captures all non-cooling water consumed would improve comparison across technologies.

c. DOE, Concentrating Solar Power Commercial Application Study: Reducing Water Consumption of Concentrating Solar Power Electricity Generation (undated), available at http://www1.eere.energy.gov/solar/

[12] NREL, Parabolic Trough Power Plant Market, Economic Assessment and Deployment website, available at http://www.nrel.gov/csp/troughnet/market_economic_assess.html.

pdfs/csp_water_study.pdf. This source captured more of the non-cooling water consumed during generation than the source cited in note b.

d. NREL, *Fuel from the Sky: Solar Power's Potential for Western Energy Supply*, NREL/SR-550-32160 (July 2002), p. 99.

e. CRS provided note.

f. Cooling ponds, which are commonly used at nuclear facilities, consume roughly 720 gal/MWh.

g. IGCC is Integrated Gasification Combined-Cycle.

Capacity factors for CSP plants with storage are highly uncertain given the early stage of CSP storage technology. As the cost of thermal storage is reduced, future parabolic trough plants could yield capacity factors greater than 70%, competing directly with future baseload combined cycle plants or coal plants.[13] Increased capacity factors mean more energy is generated at a facility, and represent an increase in the quantity of water consumed for each MW of installed capacity. Therefore, without knowing the capacity factor, projections of installed capacity in the Southwest provide incomplete information for producing reliable estimates of the water that may be required for future CSP installations.

A Trend Toward More Freshwater-Efficient Cooling

The trend for new thermoelectric generation, including CSP, in water-constrained areas is toward more freshwater-efficient cooling. These technologies may reduce, but not eliminate, the water resource impacts of CSP deployment or other expansion of electricity generation in the Southwest.

Among the factors likely to push adoption of more freshwater-efficient cooling at some CSP facilities are the scale of projected deployment, growing awareness of the water use of CSP, and ongoing research on more freshwater-efficient cooling alternatives. A February 2009 memo from the Regional Director of the Pacific West Region of the National Park Service (NPS) to the Acting State Director for Nevada of the Bureau of Land Management illustrates the trend toward more freshwater-efficient cooling. The memo identifies water availability and water rights issues as impacts to be evaluated in permitting of renewable energy projects on federal lands. The memo states: "In arid settings, the increased water demand from concentrating solar energy systems employing water-cooled technology could strain limited water resources already under development pressure from urbanization, irrigation expansion, commercial interests and mining."[14] The memo also cites rulings in 2001 and 2002 by the Nevada State Engineer identifying reluctance to grant new water rights for water-cooled power plants.

Water Use Under WGA's 2015 Deployment Goal

The Western Governors' Association has established a goal of 8 GW by 2015 for solar energy capacity.[15] If this goal is achieved through wet-cooled CSP without storage (i.e., with a 25% capacity factor), the water requirements would be roughly 43 thousand acre-feet per year

[13] Ibid.

[14] Memo from J. B. Jarvis to A. Leuders, "NPS Concerns with Concentrating Solar Power Projects on BLM Lands in Southern Nevada," Feb. 5, 2009, p. 3.

[15] WGA, "Clean Energy, a Strong Economy, and a Health Environment," June 2006, available at http://www.westgov.org/wga/publicat/CDEAC06.pdf.

(ka-f/year).[16] If the premium solar sites are selected for these first investments, they likely would be concentrated in Arizona and California. To provide a sense of scale for this water consumption, it can be compared to the overall state-level water consumption. For example, if all of the 8 GW was constructed in Arizona, the increased water demand would represent roughly 1% of the state's consumptive water use.[17]

Water Use Under NREL's 2050 Deployment Projection

NREL projected as part of its Concentrating Solar Deployment System (CSDS) that 55 GW of CSP would be deployed by 2050 and assumed that the CSP facilities would all have six hours of storage.[18] NREL estimated the mean capacity factor for these facilities at 43%.[19] If 55 GW of capacity by 2050 is achieved using wet cooling, the water requirements would be roughly 505 ka-f/year. CSP water use would be less if more water-efficient cooling is employed and if not all the facilities under the 55 GW deployment projection have thermal storage. Alternatively, electricity generated and water use could be higher if 12 hours of thermal storage are employed in some or all facilities.

Some states, like Arizona and New Mexico, currently produce more electricity than they consume, and export the surplus.[20] CSP deployment is likely to significantly increase the electricity exports from these states. According to NREL's analysis, significant amounts of the 55 GW generated would be transmitted outside of the CSP-generating states, thereby resulting in a virtual export of the water resources of the producing states to the consuming states.[21] The higher the water consumed per kilowatt-hour, the more the Southwest's limited water resources would be virtually exported to other regions. The virtual export of water raises policy questions about concentrating electricity generation and its impacts in a few counties and states while its benefits are distributed more broadly. Virtual water imports and exports, however, are not unique to electricity. For example, water is embedded in locally produced agricultural products and manufactured goods that are distributed nationally or globally.

Regional estimates of water use of CSP do not fully capture what deployment may mean for water use in the states and counties with the CSP facilities. How CSP may affect existing water uses will depend on the level of CSP capacity located in a county, the capacity factor of the

[16] The water consumption amount using a 25% capacity factor and an average of 800 gal/MWh of water intensity for wet-cooled solar thermal based on the data shown in **Table 1**.

[17] State water consumption data is from USGS, *Estimated Use of Water in the United States in 1995* (Circular 1200: 1998), which is the most recent national dataset on state- and county-level water consumption. The update of the USGS report for 2000 did not include consumption data. USGS did not collect the data due to funding constraints.

[18] The projection of 55 GW does not represent the potential full capacity using the nation's solar resources. For more information on solar potential, see M. S. Mehos and D. W. Kearney, "Potential Carbon Emissions Reductions from Concentrating Solar Power by 2030," in C. F. Kutscher, *Tackling Climate Change in the U.S.* (American Solar Energy Society, Jan. 2007), available at http://www.vcrcd.org/pdfs/Tackling%20Climate%20Change.pdf. However, there currently are no plans to utilize the majority of the solar resources of the Southwest or the nation.

[19] N. Blair, *Concentrating Solar Deployment Systems (CSDS) – A New Model for Estimating U.S. Concentrating Solar Power Market Potential* (undated), available at http://www1.eere.energy.gov/solar/review_meeting/pdfs/p_55_blair_nrel.pdf. The capacity factor used was 42.7%. For purposes of the calculations supporting the data presented in this report, 42.7% is used; however, for consistency in presentation of significant digits 43% is shown.

[20] Other states with CSP potential, like California and Nevada, consume more electricity than they generate.

[21] For projected consumers of the 55 GW, see Figure 8 in Blair, N., *Concentrating Solar Deployment Systems (CSDS) – A New Model for Estimating U.S. Concentrating Solar Power Market Potential.*

facilities, and the existing consumptive use in the county. Many of the counties identified as potential locations for CSP also were identified by EPRI as having some level of susceptibility to water supply constraints. The potential use of water by CSP in moderately constrained counties (e.g., Grant and Luna, NM) and in highly constrained counties (e.g., La Paz and Maricopa, AZ) may lead to the adoption of or requirement for more freshwater-efficient CSP facilities. For some Southwest counties with relatively low water use, large-scale deployment of CSP, even with water-efficient cooling technologies, could significantly increase the demand for water in the county (e.g., Grant, NM, and Mineral, NV).

Reducing the CSP Water Footprint

Without new water supplies becoming available and assuming that most water supplies in these arid regions are already allocated to existing uses, the water used by CSP may be purchased from existing water rights holders, or a CSP facility might develop its own supplies from impaired waters. The most likely source of water rights to purchase would come from the agricultural sector of these states. If policy makers choose to require that CSP not consume the water quantities described above, CSP facilities could reduce their freshwater footprint by employing more water-efficient cooling technologies or by cooling using alternate water supplies (i.e., impaired water supplies such as saline groundwater).

Water-Efficient Cooling Technologies

Alternatives to wet cooling can significantly reduce the freshwater footprint of CSP. Emerging cooling technologies that have the potential to consume much less freshwater include dry cooling (previously discussed), hybrid dry-wet cooling, cooling with fluids other than freshwater, and more innovative technologies (e.g., wet-surface air coolers, advanced wet cooling). The alternatives receiving most attention in the development of proposals for new thermoelectric facilities in water-constrained areas are dry and hybrid cooling.

A Department of Energy (DOE) report, *Concentrating Solar Power Commercial Application Study: Reducing Water Consumption of Concentrating Solar Power Electricity Generation*, found that dry cooling could reduce water consumption to roughly 80 gal/MWh for solar troughs and 90 gal/MWh for solar towers, compared to the cooling water consumption shown in **Table 1**.[22] However, DOE also found that electricity generation at a dry-cooled facility dropped off at ambient temperatures above 100°F. Dry cooling, thus, would reduce generation on the same hot days when summer peak electricity demand is greatest. For parabolic troughs in the Southwest, the benefit in the reduction in water consumption from dry cooling resulted in cost increases of 2% to 9% and a reduction in energy generation of 4.5% to 5%. The cost and energy generation penalties for dry cooling depend largely on how much time a facility has ambient temperature above 100°F.

In order to weigh the tradeoffs in energy generation, cost, and water use, DOE researched hybrid cooling processes that combine dry and wet cooling. The hybrid system consists of parallel wet and dry cooling facilities, with the wet cooling operating only on hot days. By using wet cooling in parallel with dry cooling on hot days, losses of thermal efficiency from dry cooling can be

[22] The undated report is available at http://www1.eere.energy.gov/solar/pdfs/csp_water_study.pdf.

reduced. How often the wet cooling is used determines how much water is consumed and the effect of hot days on thermal efficiency. DOE found that a hybrid cooling system in the Southwest using 50% of the water of wet cooling would maintain 99% of the performance of a wet-cooled facility. A hybrid cooling system using 10% of the water of wet cooling would maintain 97% of the energy performance.

Alternate Water Supply Cooling

There also may be opportunities to reduce the freshwater footprint by using alternative water supplies, such as saline water or water with otherwise impaired quality. However, information on the feasibility of alternative water supplies for cooling is limited. For large sections of the areas shown in **Figure 2** for CSP deployment, data on the depth to saline groundwater supplies is unavailable.[23] More extensive and updated information may be forthcoming in a future assessment of brackish groundwater required by Section 9507 of P.L. 111-11, the Omnibus Public Land Management Act of 2009. Other alternative water supplies, such as effluent from municipal or industrial wastewater treatment facilities, are less likely options for CSP because most of the anticipated sites for CSP deployment are remote from urban development.

Concluding Observations

Growing populations and changing values have increased demands on water supplies and river systems, resulting in water use and management conflicts throughout the country, particularly in the West. In many western states, agricultural water needs can be in direct conflict with urban needs, as well as with water for thermoelectric cooling, threatened and endangered species, recreation, and scenic enjoyment. Debate over western water resources revolves around the issue of how best to plan for and manage the use of this renewable, yet sometimes scarce and increasingly sought after, resource. Traditional users of water supplies often are wary of new water demands that may compete or result in reduced deliveries to farms (leading to lost agricultural production). Deployment of CSP would add an additional demand to existing freshwater competition in the Southwest.

As indicated in the analysis herein, there remains significant uncertainty about where, how much, and what type of CSP capacity may be installed. Technological advances in CSP, thermal storage, and cooling technologies also may change the water intensity of any CSP that is deployed. Water resource data gaps on current and projected non-CSP water consumption and on availability of impaired water supplies add uncertainty to analyses of the potential significance of CSP freshwater use and alternatives to its use. For these reasons, any estimate of how much water may be consumed by CSP at the regional, state, or county level is highly uncertain.

Any shift of freshwater resources to CSP from an existing use would have costs and benefits. For example, if the water is shifted from agricultural use to CSP cooling, the region would forgo the benefits of that agricultural production. Alternatively, the water could also become available for use in CSP through improvements in agricultural or municipal and industrial water efficiency. CSP, however, would bring jobs and investments to the Southwest while producing electricity

[23] See USGS, *Ground-Water Availability in the United States* (Circular 1323: 2008), p. 27.

(without significant greenhouse gas emissions) that could be put to use by municipal, industrial, and other consumers in a broader area of the country.

How to manage existing and new water demands is largely up to the states. Most electricity siting and water planning, management, and allocation decisions are delegated to the states. Federal agencies support state water management efforts through data collection and technology research.[24] Whether and how the federal government should promote water conservation, efficiency, markets, and regional- and state-level planning and collaboration is a matter of debate, and actions in these areas often occur on a piecemeal or ad hoc basis. At the same time, federal policies (e.g., energy, agriculture, and tax policies) can affect water-related investments and water use, and operations of federal facilities can affect the water available for allocation.

[24] According to a General Accounting Office (GAO, now the Government Accountability Office) survey, state water managers ranked water data from more locations as second (after financial assistance to increase storage and distribution) among federal actions that could best help states meet their water resource needs. GAO, *Freshwater Supply: States' View of How Federal Agencies Could Help Them Meet the Challenges of Expected Shortages*, GAO-03-514 (July 2003) p. 6.

Appendix. Illustrative Scenario of State and Local Water Resources Implications in 2050

CRS analyzed NREL's CSP deployment scenario for 2050 in order to evaluate potential state and local water resource implications. CRS chose NREL's scenario as the basis for this analysis because it provided county-level deployment estimates; other available renewable deployment projections are at much larger geographic scales, typically at the region or state level. A major drawback of using a deployment scenario that extends to 2050 is that it is highly speculative. At the same time, water resource planning, projects, and decisions often are performed and evaluated on time scales encompassing many decades.

Illustrative Scenario of State Water Use Under 2050 Deployment Projection

NREL projected as part of its Concentrating Solar Deployment System (CSDS) that 55 GW of CSP would be deployed by 2050 and assumed that the CSP facilities would all have six hours of storage. NREL estimated the mean capacity factor for these facilities at 43%.[25] If 55 GW of capacity by 2050 is achieved using wet cooling, the water requirements would be roughly 505 thousand acre-feet per year (ka-f/year).[26] CRS developed a scenario, shown in **Table A-1**, for how the 55 GW of CSP capacity might be distributed across the five states that are identified for CSP deployment in **Figure 2**. **Table A-1** shows an illustrative scenario of water use in each state if wet cooling is used. CSP water use would fall if more water-efficient cooling is employed and if not all the facilities under the 55 GW deployment projection have thermal storage. Alternatively, water use could be higher if 12 hours of thermal storage are employed in some facilities.

The scenario used in **Table A-1** is based on the NREL projection in **Figure 2**; as more current projections of how much and where CSP may be deployed are released, any estimates of state water use impacts would change. For example, if updated projections show that New Mexico, Texas, and Colorado have more CSP deployment than shown in **Figure 2**, the CSP water footprint may be greater in those states than shown in **Table A-1**. Similarly, if deployment in Arizona and California is less than shown in **Figure 2**, the CSP water footprint in these states would be smaller. That is, if CSP deployment by 2050 in Arizona were to be 9 GW, rather than the 18 in the scenario in **Table A-1**, CSP water use would be half of the 3.9%.

[25] N. Blair, *Concentrating Solar Deployment Systems (CSDS) – A New Model for Estimating U.S. Concentrating Solar Power Market Potential* (undated), available at http://www1.eere.energy.gov/solar/review_meeting/pdfs/p_55_blair_nrel.pdf. The capacity factor used was 42.7%. For purposes of the calculations supporting the data presented in this report, 42.7% is used; however, for consistency in presentation of significant digits 43% is shown.

[26] USGS, *Estimated Use of Water in the United States in 1995* (Circular 1200: 1998).

Table A-1. Illustrative 2050 Water Scenario for NREL's 55 GW CSP Deployment Projection with Storage

State	CSP Capacity (GW) in 2050[a]	Wet-Cooled CSP Water Consumption (ka-f/yr) [b]	1995 State Freshwater Consumption (ka-f/yr)[c]	Wet Cooled CSP as % of 1995 State Use	Dry Cooled CSP as % of 1995 State Use[d]
Arizona	18	165	4,290	3.9%	0.4%
California[e]	25	230	28,560	0.8%	< 0.1%
Nevada	3	28	1,500	1.8%	0.2%
New Mexico	8	73	2,220	3.3%	0.3%
Texas	1	9	11,760	< 0.1%	< 0.1%
Total	*55*	*505*			

Source: CRS compiled using noted data.

Notes:

a. CRS derived using a coarse approximation of the distribution of CSP deployment by 2050 as projected by NREL and shown in **Figure 2**.

b. A capacity factor of 43% and an average of 800 gal/MWh of water intensity for wet-cooled CSP were used.

c. Water consumption data from USGS, *Estimated Use of Water in the United States in 1995* (Circular 1200: 1998), More recent USGS consumption data is not available.

d. 80 gal/MWh of water intensity used for dry-cooled CSP.

e. California already has a in place a State Water Resources Control Board Resolution from 1975 stating that "use of fresh inland waters for power plant cooling will be approved by the Board 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." The resolution is available at http://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/1975/rs75_058.pdf.

The illustrative scenario of potential water consumption from the 55 GW is sensitive to the capacity factor used. The total water consumption varies from 483 ka-f/year for a capacity factor of 41% to 541 ka-f/year for a capacity factor of 46%; these capacity factors were the upper and lower ends of the range used in NREL's 55 GW analysis.[27] NREL varied the capacity factor to capture differences in energy production anticipated based on the solar resource at the different locations in the Southwest. Uncertainty about where CSP facilities might be constructed, whether these facilities will perform at the capacity factors currently assumed, and which types of cooling technologies these facilities will use contribute to there being little known about the future water resource impacts of CSP deployment.

[27] The capacity factors used were 40.9% and 45.7%. For purposes of the calculations supporting the data presented in this report, 40.9% and 45.7% are used; however, for consistency in presentation of significant digits 41% and 46% are shown.

Illustrative Scenario of County Water Use Under 2050 Deployment Projection

The state-level scenarios in **Table A-1** do not fully capture what a 55 GW deployment may mean for water use in the counties with the CSP facilities. CRS used **Figure 2** to develop a scenario of county-level CSP deployment and its water use for a sample of counties. The results, shown in **Table A-2**, illustrate that the local effect will depend on the capacity located in the county, the capacity factor of the facilities, the type of cooling used, and the existing consumptive use in the county. **Table A-2** illustrates that, for a number of counties, the potential water demand of wet-cooled CSP could be significant in 2050. The calculations in **Table A-2** demonstrate why there is interest in using non-freshwater sources and in adopting more water-efficient cooling techniques, and why regulators in some states, such as California, may be reluctant to permit wet-cooled facilities.

All of the counties in **Table A-2** were identified to have some susceptibility to water supply constraints. **Table A-2** illustrates that, in some counties (e.g., Grant, NM, and Mineral, NV), water use of CSP under the NREL deployment projections may result in a notable change in county water use even if dry cooling is employed. The potential use of water by CSP in moderately constrained counties (e.g., Grant and Luna, NM) and in highly constrained counties (e.g., San Bernardino, CA , and La Paz and Maricopa, AZ) may lead to the adoption of or requirement for freshwater-efficient CSP facilities.

Table A-2. Illustrative 2050 Water Scenario for Select Counties Using NREL's 55 GW CSP Deployment Projection with Storage

County, State	Capacity Factor	CSP Capacity (GW)[a]	Wet-Cooled CSP Water Use (ka-f/yr)[b]	Dry-Cooled CSP Water Use (ka-f/yr)[c]	1995 County Freshwater Consumption (ka-f/yr)[d]	Wet Cooled CSP as % of 1995 County Use	Dry Cooled CSP as % of 1995 County Use
La Paz, AZ	0.25	3.1	17	2	382	4%	<1%
La Paz, AZ	0.43	3.1	28	3	382	7%	<1%
Maricopa, AZ	0.25	15	81	8	1,518	5%	<1%
Maricopa, AZ	0.43	15	138	14	1,518	9%	<1%
Yavapai, AZ	0.25	3.1	17	2	58	29%	3
Yavapai, AZ	0.43	3.1	28	3	58	49%	5
Riverside, CA	0.25	15	81	8	1,124	7%	<1%
Riverside, CA	0.43	15	138	13	1,124	12%	1%
San Bernardino, CA	0.25	15	81	8	314	26%	3%
San Bernardino, CA	0.43	15	138	14	314	44%	4%
Tulare, CA	0.25	1.3	7	<1	2,698	<1%	<1%
Tulare, CA	0.43	1.3	12	1	2,698	<1%	<1%
Mineral, NV	0.25	1.3	7	<1	21	33%	3%
Mineral, NV	0.43	1.3	12	1	21	57%	6%
Grant, NM	0.25	3.1	17	2	31	54%	5%
Grant, NM	0.43	3.1	29	3	31	92%	9%

County, State	Capacity Factor	CSP Capacity (GW)[a]	Wet-Cooled CSP Water Use (ka-f/yr)[b]	Dry-Cooled CSP Water Use (ka-f/yr)[c]	1995 County Freshwater Consumption (ka-f/yr)[d]	Wet Cooled CSP as % of 1995 County Use	Dry Cooled CSP as % of 1995 County Use
Luna, NM	0.25	3.1	17	2	85	20%	2%
Luna, NM	0.43	3.1	29	3	85	34%	3%
Hudspeth, TX	0.25	0.45	2	<1	238	1%	<1%
Hudspeth, TX	0.43	0.45	4	<1	238	2%	<1%

Source: CRS compiled using data noted below.

Notes:

a. CRS derived using a coarse approximation of the distribution of CSP deployment by 2050 as projected by NREL and shown in **Figure 2**.

b. 800 gal/MWh of water intensity used for wet-cooled CSP.

c. 80 gal/MWh of water intensity used for dry-cooled CSP.

d. County water consumption data from USGS, *Estimated Use of Water in the United States in 1995* (Circular 1200: 1998). Data was not available online, but obtained by CRS from USGS.

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