California's Energy-Water Nexus: Water Use in Electricity Generation

***Dana Larson, Cheryl Lee, Stacy Tellinghuisen,** and **Arturo Keller** — Bren School of Environmental Management and Science, University of California, Santa Barbara*

Water and energy are inextricably linked. Large amounts of water are needed for energy production, and large amounts of energy are needed for the extraction, conveyance, treatment, and distribution of water. Historically, energy and water issues have been examined independently, which has led to:

- planning for future electricity production without considering water needs; and
- planning for a future domestic potable water supply and wastewater treatment with the assumption that electricity will be readily available and affordable.

In the future, however, both the scarcity of freshwater and the cost of energy will likely become limiting factors of economic and population growth. This is particularly critical in California and other arid Southwestern states, where population is projected to grow dramatically and climate change models suggest that freshwater supplies may decrease significantly. Integrated planning between the energy and water sectors therefore will be essential to meet rising demands for both resources.

How Much Water for Electricity?

We reviewed peer-reviewed literature, industry and government sources, and primary research to collect quantitative water requirements pertaining to each step of the electricity generation process. The water input steps considered were different for each type of generation but generally included agriculture, mining, transportation, makeup water, processing, cooling, cleaning, evaporative losses, and other. For example, water is required at several points in the process of generating electricity from coal. Initially, water is required for extraction (mining), processing (washing), fuel conversion (gasification), and finally cooling.

The following primary energy sources were analyzed: bioenergy, coal, geothermal, hydroelectric, natural gas, nuclear, oil, solar, and wind. High and low estimates for both water withdrawn and water consumed were included in the data collection process. To ensure the validity of the data, the 2005 water withdrawals for electricity generation were projected for four counties in California and compared to U.S. Geological Survey (USGS) and California Department of Water Resources (DWR) thermoelectric water withdrawal estimates for the same counties. Projected water requirements closely agreed with USGS and DWR values for coastal counties. The projection for the one inland county showed some discrepancy, likely due to the large amount of reclaimed water used for power plant cooling there.

> *While geothermal and coal constitute less than a quarter of the generation capacity …, they account for almost 90 percent of the freshwater requirements.*

The data were used to project the total water needs for California's potential future energy portfolios under the 2010 and 2020 renewable portfolio standards (RPS; see sidebar below). In addition, scenarios were created for the year 2020 that altered the primary energy sources, electricity generation technologies, and cooling technologies. These scenarios included: 1) a fossil fuel-focused scenario in which future electrical generation growth was limited to natural gas and coal; 2) an advanced technologies scenario in which integrated gasification combined cycle (IGCC) and dry cooling technologies were applied to the 2020 RPS portfolio; and 3) a water-efficient primary energy scenario that relies on the primary energy sources that our initial research identified as water-efficient (rooftop solar photovoltaic, wind, and waste-based bioenergy).

This analysis considered only freshwater requirements for power generation, thus seawater-cooled thermoelectric power plants and hydroelectric facilities were excluded. Although the total volume of seawater withdrawn for power generation in California is far greater than that for freshwater, greater competition exists

Renewable Portfolio Standards

To promote sustainable energy production and help boost the renewables market as it matures, 24 states to date have adopted renewable portfolio standards (RPS). These require sellers of electricity to have a certain percentage of "renewable power" in their mix. RPS policies usually mandate a gradual increase in the percentage over a number of years, and often involve a trading mechanism whereby companies can sell credits to those who haven't met their requirements.

Renewable energy sources typically include wind, geothermal, biomass, solar, hydropower, and ocean-based energy (using offshore wind, ocean waves, currents, or tides).

The California RPS policy, the most stringent in the United States, was established in 2002, requiring retail sellers of electricity to purchase 20 percent of their electricity from renewable resources by 2017. Because the state had already been generating around 10 percent of its electricity consumption by renewables and the program enjoyed considerable early success, the time frame was accelerated to achieve the 20 percent goal by 2010, and a new goal of 33 percent was set for 2020.

for freshwater resources. Further, while seawater cooling may appear to be a likely alternative to the use of freshwater in energy generation, growing concerns about negative impacts to coastal ecosystems have shifted interest away from this cooling method.

And the Results Are...

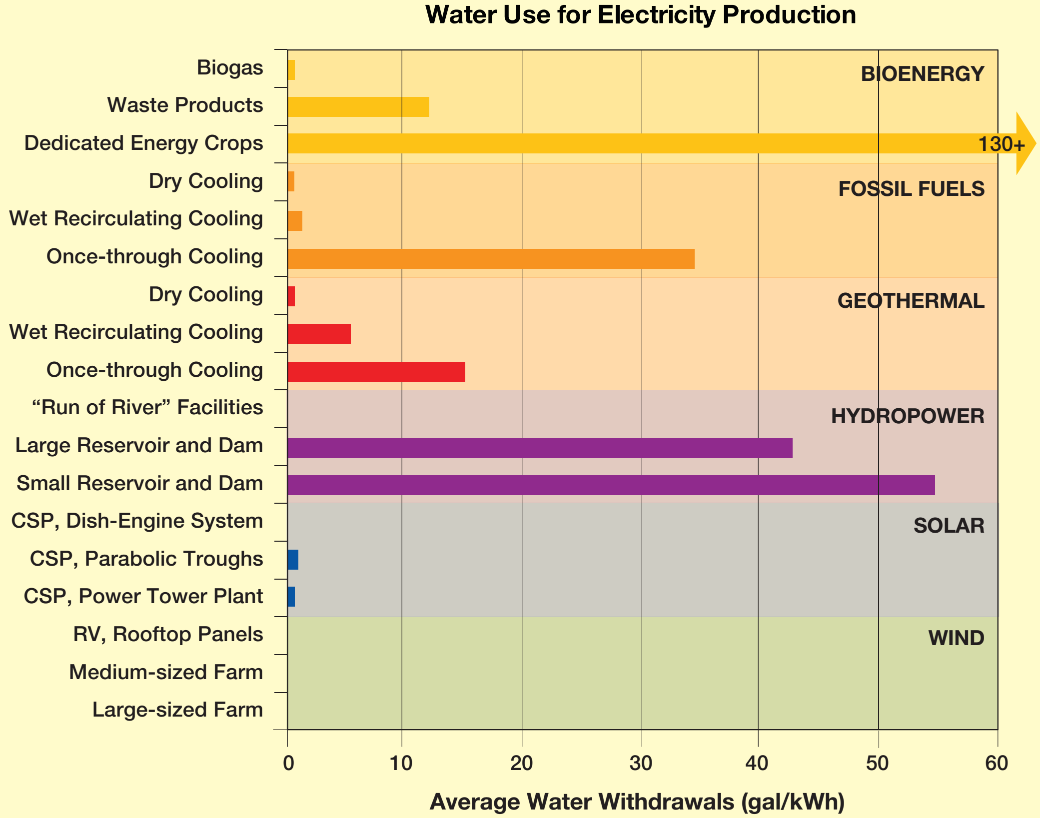
Water requirements vary greatly, depending on the primary energy source, conversion technologies, and cooling technologies used (see figure, right). Overall, the data showed that the biggest water users are bioenergy derived from dedicated energy crops (based on average values for irrigated crops), hydroelectric facilities, and thermoelectric facilities using once-through cooling. Waste-based bioenergy, thermoelectric facilities using dry cooling, solar photovoltaics, and wind turbines require the least water.

Alternative Energy Scenarios

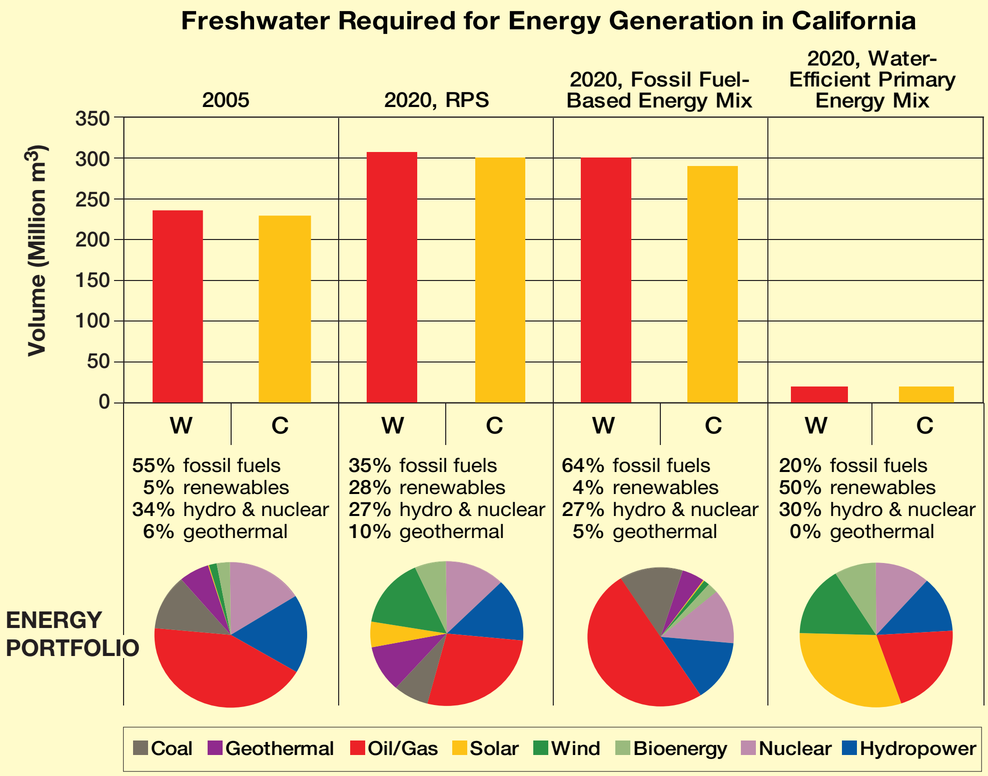
When the water requirements were applied to future energy scenarios, the total amount of water required varied (see figure below right). Surprisingly, the fossil fuel-based scenario projected for 2020 requires less water than that required by the 2020 RPS. A closer analysis of the breakdown of water use for each of the different energy sources within these two scenarios reveals a large proportional contribution of geothermal and coal. While these two primary energy sources constitute less than a quarter of the generation capacity of the 2020 RPS and fossil fuel based scenarios, they account for almost 90 percent of the freshwater requirements of these scenarios.

Thus, altering the generation and cooling technologies or primary energy sources can decrease freshwater withdrawals and consumption significantly below the 2020 RPS-based projected energy mix. Future water requirements for electrical generation can be reduced, not only below future projections, but even below current water requirements. By incorporating technologies such as dry cooling and coal gasification into the RPS 2020 scenario, California's projected annual freshwater withdrawal and consumption requirements decrease by 66 percent. By relying on more water-efficient primary energy sources such as solar photovoltaic, wind, and waste-

see California's Nexus, page 30



Water requirements are highest for electricity generated from irrigated crop-based biomass, hydroelectric power, and for thermoelectric generation using once-through cooling technology. Note: not all energy crops are irrigated, and regional irrigation differences are great. CSP = concentrating solar power (power towers and parabolic trough plants).



Average water required (W = withdrawals, C = consumption) for electricity generated in 2005 and for three future (2020) scenarios. Although nuclear and hydropower are included in the portfolios (assumes existing infrastructure will continue to be utilized), they are not considered in the water requirements totals because California's nuclear plants are seawater cooled and water use by hydroelectric facilities counts all water flowing through turbines, a very different metric than other water requirements for generation.

California's Nexus, continued from page 21
based bioenergy, we project California's water withdrawals and consumption to decrease even further, up to 90 percent.

To make the collected data available in a more user-friendly manner, a Web-based tool was created to calculate the estimated water requirements (both withdrawn and consumed) of a given portfolio (see sidebar).

A Clear Benefit to Water Efficiency in Energy Planning

There are several key conclusions of this analysis. First, a water-efficient energy portfolio demands the right mix of primary energy sources, conversion technologies, and cooling technologies. Utilities should therefore focus on increasing investment in water-efficient electricity generation such as solar photovoltaics, wind power, and coal gasification systems.

Second, policies that encourage conservation of water can greatly reduce future water requirements. For example, issuing conservation credits to energy utilities that implement programs to reduce water use will help reduce both water and electricity consumption. Integration of water and energy infrastructure planning also offers several distinct benefits. Co-locating wastewater treatment facilities and power plants facilitates the increased use of reclaimed water in power plants, reducing potable water consumption and providing a reliable water supply.

Finally, many research gaps still exist. A thorough life-cycle assessment of electricity generation, including water use in facility construction, is needed to understand the full water requirements of electricity generation. Additionally, as water-efficient energy portfolios are developed, the feasibility must be determined, assessing both the availability of energy resources and patterns of demand.

Several issues must be considered in the integration of energy and water planning. First, relying on water-efficient renewable sources of energy decreases water use and may decrease greenhouse gas emissions and provide greater political security.

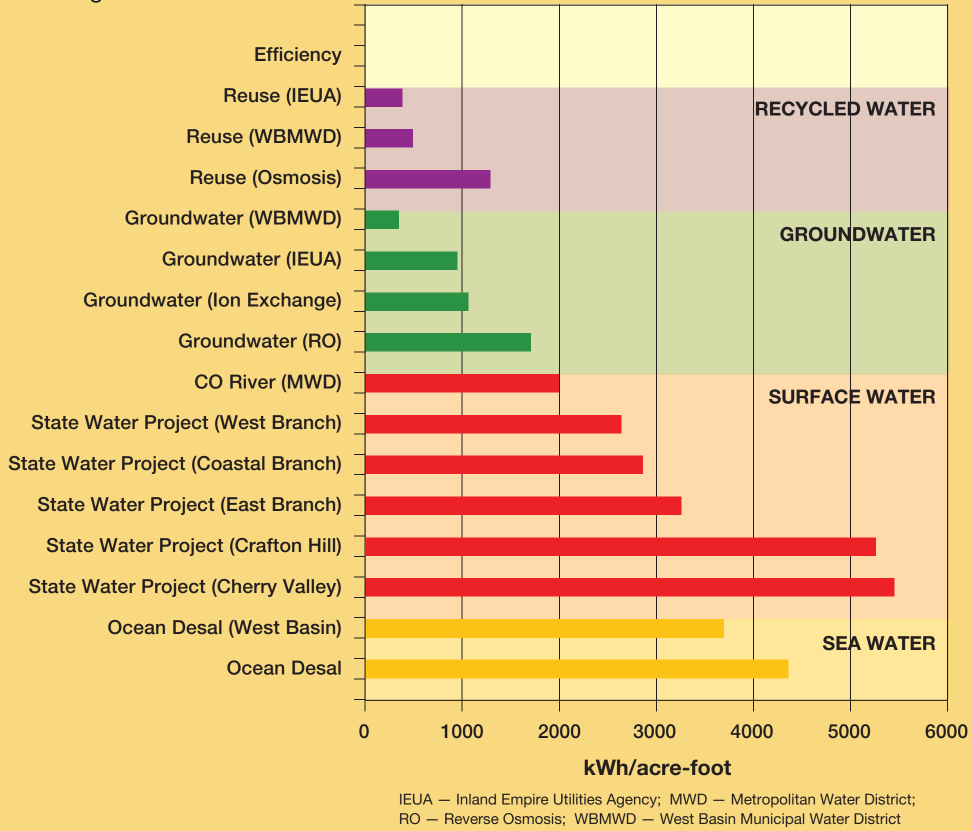
The Energy Intensity of Water Supplies

***R. C. Wilkinson** – University of California at Santa Barbara*

The total energy embedded in a unit of water used in a particular place varies with location, source, and use. The energy intensity of water is the total amount of energy, calculated on a whole-system basis, required for the use of a given amount of water in a specific location. All steps in the process, starting with initial extraction from a natural source through conveyance, treatment, distribution, end-uses, waste collection, treatment, and discharge are included.

A spreadsheet-based computer model (available from the author) calculates both individual and cumulative energy inputs of each process in the water system to determine its energy intensity. The table below illustrates the range of energy intensities for various water systems in Southern California.

The energy intensity calculator is available for no charge from the author. Contact R.C. Wilkinson at wilkinson@es.ucsb.edu.



Energy intensity of selected water supply sources in Southern California.

This transition to alternative sources of electricity must be accomplished, however, in a manner that will not compromise the reliability of our energy supplies. In addition to the impacts of electricity generation on water resources, we must consider other environmental impacts. For example, covering the deserts of California with solar panels may reduce pollution and conserve water, but may have significant impacts to regional biodiversity and ecosystems through habitat loss. Finally, impacts on water resources may be region-specific. As we see in the bioenergy sector, the production of dedicated energy crops may be limited in the arid Southwest, but may be more viable in wetter climates of the United States.

As freshwater resources will likely become more constrained in the future and may limit electricity generation, water efficiency must be considered in energy planning. This analysis provides a tool to support integrated planning between energy and water utilities, and to help government agencies integrate water considerations into planning for future energy supplies.

Contact: Dana Larson at dlarson@bren.ucsb.edu

Reference

Dennen, A., D. Larson, C. Lee, J. Lee, and S. Tellinghuisen, 2007. California's Energy-Water Nexus: Water Use in Electricity Generation. Report to be published at University of California at Santa Barbara.