Water Use

Water use for thermoelectric power generation has been a growing concern in recent years. The large amount of water consumed for power generation, combined with the trend for greater demand promises to increase consumption in future years. In this section we evaluate water use in various electric power generation technologies, compare water use for power generation with other uses, and examine alternate sources of water for power generation.

A. Water Use in Electric Power Generation

The availability and use of water is a key factor in electric power generation. All thermo-electric power generation requires cooling from a variety of methods, the cooling tower structure being the most common today. In cooling towers, evaporation of water is used to cool the steam leaving the turbine, and this evaporation is the main source of water consumption.

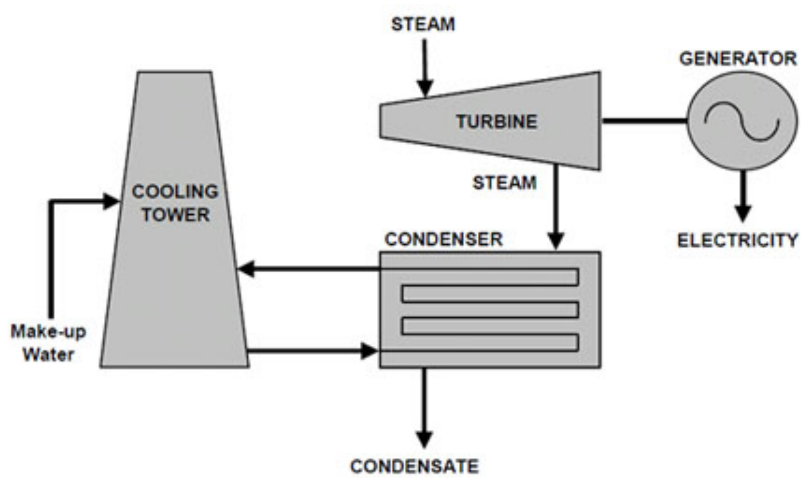
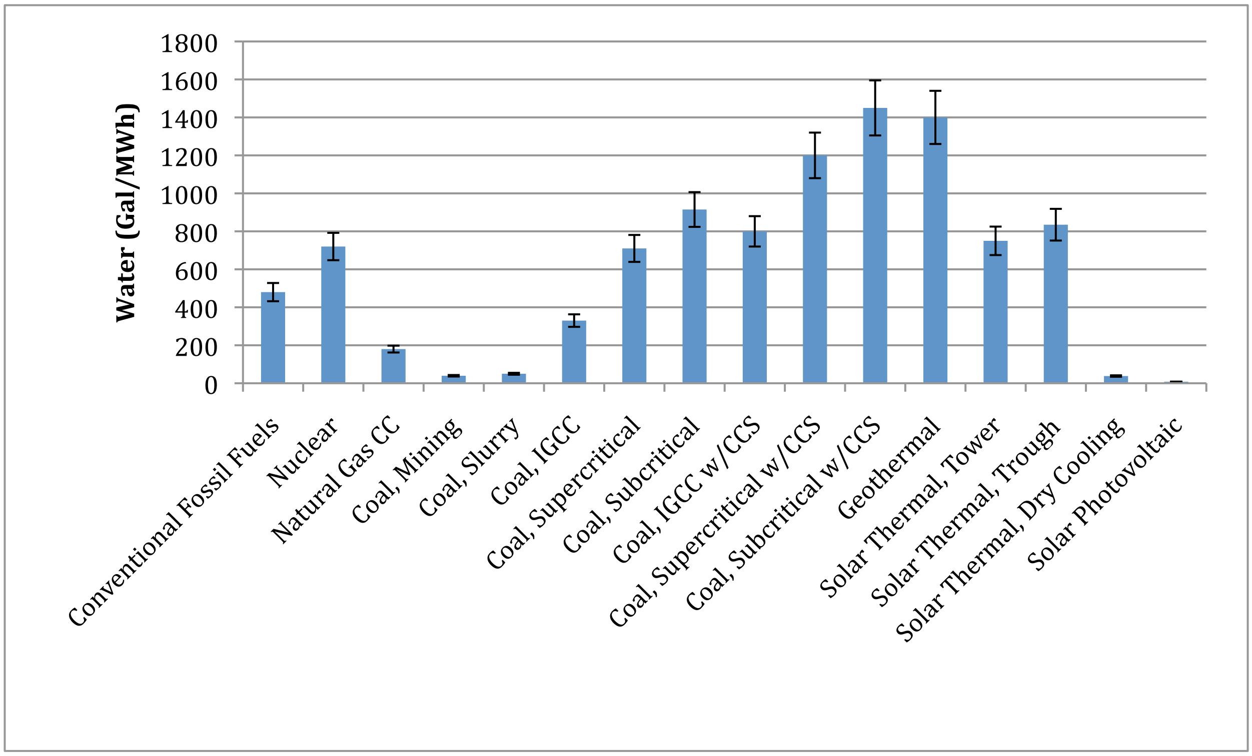


Diagram of a Cooling Tower[1]

For both solar thermal electricity and photovoltaics a small amount of water is also necessary for panel washing. However, because it directly generates electricity from sunlight unlike thermoelectric power generation, photovoltaics do not require any additional water consumption.

The below chart and table indicate water consumption per unit energy generated for various electric power generation technologies.



Water Consumption for Electric Power Generation

Power Generation Type	Water Usage (Gal/MWh)	References
Fossil/biomass/waste-fueled steam, cooling towers	~480	(2)
Nuclear	~720	(2)
Natural Gas CC	~180	(2)
Coal, Mining	~5-74	(3)
Coal, Slurry	30-70	(3)
Coal, IGCC	~330	(3,4, 5)
Coal, Supercritical	~710	(4,5)
Coal, Subcritical	~915	(4,5)
Coal, IGCC w/CCS	~700	(4,5)
Coal, Supercritical w/CCS	~1100	(4,5)
Coal, Subcritical w/CCS	~1300	(4,5)
Geothermal	~1400	(3)
Solar Thermal, Tower	~750	(6)
Solar Thermal, Trough	750-920	(6)
Solar Thermal, Dry Cooling	~8-70	(6)
Solar Photovoltaic	~8	(6)

References

(1) Torcellini et. al. "Consumptive Water Use for US Power Production" NREL, 2003. http://www.nrel.gov/docs/fy04osti/33905.pdf
(2) EPRI, Electric Power Research Institute. " Water and Sustainability (Volume 3): U. S. Water Consumption for Power Production—The Next Half Century." 2002. http://mydocs.epri.com/docs/public/000000000001006786.pdf
(3) U.S. Department of Energy. "Energy Demands on Water Resources." 2006. http://www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf
(5) Simulations from IECM, Integrated Environmental Control Model. 2010. http://www.iecm-online.com/
(6) U.S. Department of Energy. "Concentrating Solar Power Commercial Application Study." DoE, 2009. http://www1.eere.energy.gov/solar/pdfs/csp_water_study.pdf

Links for further reading

Additional links to be provided after the forum.

Comparison with Domestic and Agricultural Water Use

Comparing water use for electric power generation with direct domestic use on a per capita basis provides some perspective for how this water use compares in scale. According to the U.S. Geological Survey, the average domestic per capita water usage in the Southwest U.S. for users connected to public supply is 203.3 gal/day or 74,204 gal/yr[1]. The per capita energy consumption average for the southwest US is 812 kWh/month, or 9.714 MWh/yr[2]. Current per capita water use from energy consumption: 4332 gal/yr. Using only Solar Thermal with wet cooling to meet the 2020 California RPS standards would increase this to 4,799 gal/yr, less than domestic water use from: Toilet (8,014 gal/yr), Clothes Washing (6,450 gal/yr) and comparable to that from: Faucet (4,670 gal/yr), Shower (5,040 gal/yr)[3].

References

(1) USGS. "Estimated Use of Water in the United States in 2000." 2000.
http://pubs.usgs.gov/circ/2004/circ1268/pdf/circular1268.pdf
http://pubs.usgs.gov/circ/2004/circ1268/htdocs/table05.html
(2) US Energy Information Administration. "Electric Sales, Revenue, and Average Price 2008." 2008.
http://www.eia.doe.gov/cneaf/electricity/esr/esr_sum.html
(3) American Water Works Association Research Foundation. "Residential End Uses of Water." 1999. http://www.aquacraft.com/Publications/resident.htm

Links for further reading

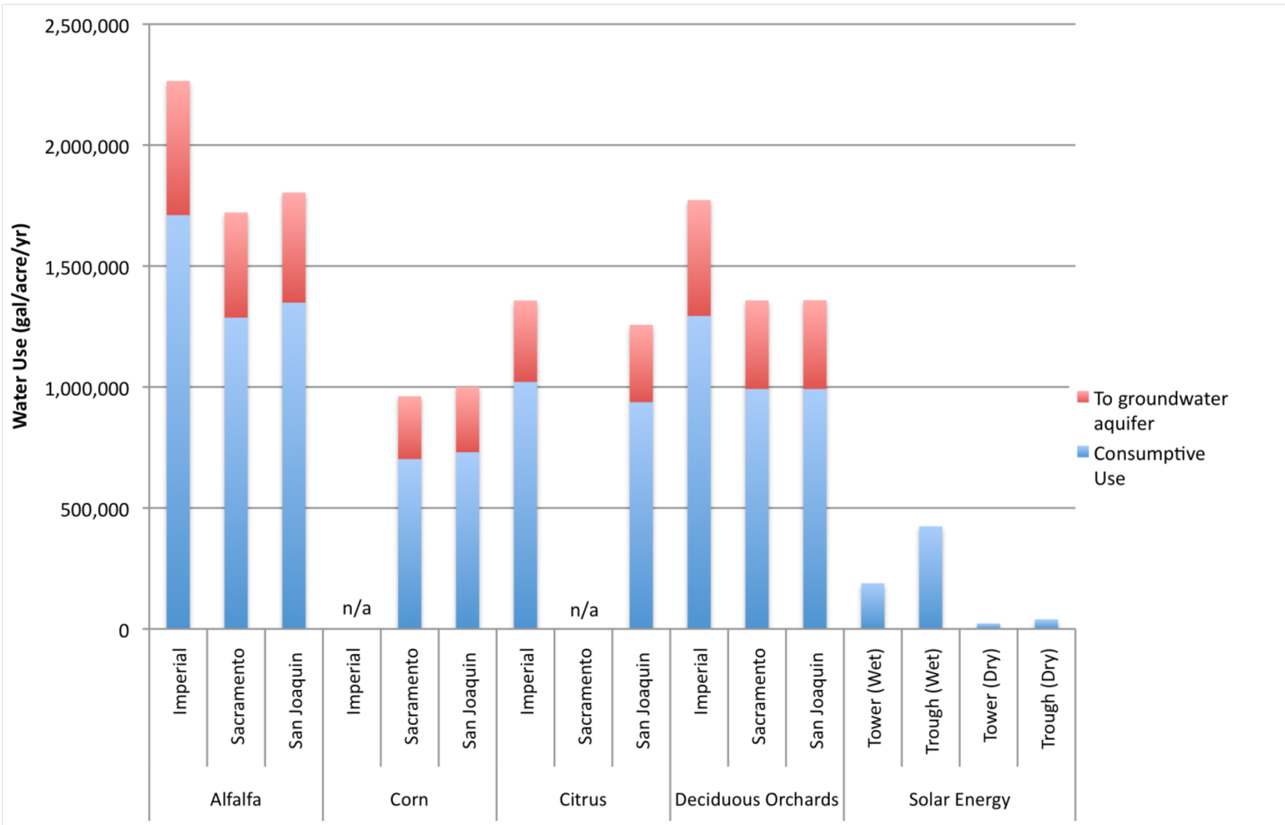
1. USGS Water Use Data: http://water.usgs.gov/watuse/
2. USGS Colorado Golf Course Water Use study: http://pubs.usgs.gov/of/2008/1267/
3. American Water Works Association: http://www.awwa.org/
4. AWWA Water Use Statistics: http://www.drinktap.org/consumerdnn/Home/WaterInformation/Conservation/WaterUseStatistics/tabid/85/Default.aspx

A. Comparison with Agricultural Water Use

Agricultural crops and thermoelectric-power are major consumers of water. Irrigation accounted for 31% of total water withdrawals in the U.S. in 2005. Of the total U.S. withdrawals for irrigation, 85% were in the 17 conterminous Western States, where annual precipitation typically averages less than 20 inches per year. Thermoelectric-power accounted for 49% of total withdrawals in 2005, with 92% attributed to power plants using once-through cooling and the remaining 8% to power plants with recirculating systems. About 81% of power plants using recirculating cooling systems reported that 50% or greater of the water use was consumptive[1].

Case Study—California

The study focused on three important agricultural regions in California, the Imperial Valley, the Sacramento Valley, and the San Joaquin Valley. Annual applied water and consumptive water use for four crops were estimated. Applied water is the amount of water applied to the crop through irrigation. Consumptive water is the actual water demand of the crop, which is assumed to be the amount of water evapotranspired by the crop. The difference between applied water use and consumptive water use is the amount of irrigation water that runs off a field to a stream or percolates through the soil and eventually enters the groundwater aquifer, thus contributing to groundwater recharge. The figure below shows estimated crop water usage, along with estimated water requirements for large-scale solar thermal energy systems for comparison.



Estimates of water use for four crops grown in the Imperial Valley, Sacramento Valley, and San Joaquin Valley, compared to water required for solar thermal energy systems. (Crop water usage was calculated from California Irrigation Management Information System (CIMIS) data[2] and solar water usage was calculated from DOE reports[3].)

References

(1) Kenney, J.F. et al. 2009. Estimated Use of Water in the United States in 2005. U.S. Geological Survey. Accessed Mar 2010. http://pubs.usgs.gov/circ/1344/
(2) CIMIS Data. Accessed Mar 2010. http://wwwcimis.water.ca.gov/cimis/data.jsp
(3) U.S. Department of Energy. "Concentrating Solar Power Commercial Application Study." DOE, 2009. http://www1.eere.energy.gov/solar/pdfs/csp_water_study.pdf

Links for further reading

1. California Irrigation Management Information System (CIMIS). ET Overview. http://www.cimis.water.ca.gov/cimis/infoEtoOverview.jsp
2. CIMIS Agricultural Resource Book. 2000. http://wwwcimis.water.ca.gov/cimis/pdf/CIMIS_ag_resource.pdf;jsessionid=9ACF06A094A06B456F8D8486D00150E3
3. “Using Reference Evapotranspiration (ETo) and Crop Coefficients to Estimate Crop

Evapotranspiration (ETc) for Agronomic Crops, Grasses, and Vegetable Crops." Division of Agriculture and Natural Resources. Leaflet 21427,21428. Can be requested from Department of Water Resources at http://wwwcimis.water.ca.gov/cimis/resourceTechRefsUcd.jsp.

B. Use of Brackish/Waste Water

Degraded water is defined as surface water, groundwater, treated municipal effluent or industrial process water which is not suitable for potable use because of natural or manmade contaminations[1]. Degraded or reclaimed water can be used for a variety of purposes in power plants. The most common usage of reclaimed water is for cooling tower makeup, but it is also used for cooling ponds, air scrubbers, boiler feed water, and scrubber water[2].

Regulations

The use of reclaimed water is regulated by the Clean Water Act, which requires municipal wastewater treatment facilities to obtain a permit issued under the National Pollutant Discharge Elimination System program before it can discharge treated wastewater[3]. Reclaimed water must meet secondary standards which are set by the NPDES through 40 CFR 133:102[4]. Each state has different regulations concerning the use of recycled water. In California, this is controlled by Title 22, Division 4, Chapter 3, Article 3 under Uses of Recycled Water[5].

Problems

Common operating cooling water problems are: fouling- accumulation of unwanted material on solid surfaces, corrosion - the disintegration of an engineered material into its constituent atoms due to chemical reaction with its surroundings, scaling that forms as a result of calcium and magnesium ion deposits on the units of a cooling system, as well as biological contaminates. This causes the formation of a core, which forms insulation later on the heat exchanger[6].

Treatment

Wastewater requires treatment prior to use. Pre-treatment, side stream and treatment equipment are employed to protect heat transfer surfaces (especially the main condenser), to lower the mineral content of make-up and/or circulating water e.g. calcium, magnesium, alkalinity, phosphates, silica, and to remove suspended material from make-up/and or circulating water. Post treatment in the form of blowdown reduction is usually considered for inland plants where disposal options are limited to evaporation ponds[7].

Costs

Degraded water is more expensive to use because it has higher mineral content, and so leads to lower cycles of concentration and higher rates of blowdown, meaning more water is used. Additionally, the treatment process increases the cost due to the chemicals used, the increased electricity usage, and the increased capital expenditure that is needed. In comparing central valley, desert, and coastal locations, we find that central valley and desserts tend to be more costly due to scarcity of water. Thus, lower quality water with higher mineral content is used, resulting in increased transportation and treatment costs, as well as higher disposal volumes[7].

Type of Degraded Water	Produced Water	Agricultural Return Water	Reclaimed Water
Location	Central Valley	Desert	Coastal
Costs Degraded : Fresh	1.73	2.07	1.14
Daily Unit Costs (Degraded : Fresh) ($/1000 gallons)	$4.77 : $2.77	$5.65 : $2.73	$1.87 : $1.65

A case study of Redhawk Power Station reveals how reclaimed water can be used in power plants. The water in this study comes from effluent water from Phoenix that is piped to Palo Verde for treatment. A portion of this water is used by Redhawk Power station in their cooling towers. Another portion is cleaned via reverse osmosis to produce water of high quality (1-4 microsiemens/cm) to be used in their steam turbine. All of the water is reused in the plant through the ZLD (Zero Liquid Discharge) process, which precipitates all soluble compounds through evaporation and crystallization, and frees up the water to be reused in the cooling tower. The solids are trucked away from the facilities[8].

References

(1) "O'Hagen, J., and K. Zammit. Use of Degraded Water Sources as Cooling Water in Power Plants. Tech. Palo Alto/Sacramento: Electric Power Research Institute and Public Interest Energy Research Program, 2003", p 1-2. http://www.energy.ca.gov/reports/2004-02-23_500-03-110.PDF

(2) Veil, J.A., 2007, Use of Reclaimed Water for Power Plant Cooling, ANL/EVS/R-07/3, prepared by the Environmental Science Division, Argonne National Laboratory, Argonne, Illinois, for the U.S. Department of Energy, National Energy Technology Laboratory, Aug ANL/EVS/R-07/3. Accessed March 2010. http://www.ead.anl.gov/pub/dsp_detail.cfm?PubID=2148

(3) http://epw.senate.gov/water.pdf

(4) EPA (U.S. Environmental Protection Agency, "Title 40 Protection of the Environment," US Environmental Protection Agency. Accessed March 2010. http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=5856171cddf65974c0440f4ab8c97a25&rgn=div8&view=text&node=40:21.0.1.1.20.0.16.3&idno=40

(5) California Code of Regulations – Title 22: Social Security, Division 4, Chapter 3, Article 3. California Office of Administrative Law. Accessed March 2010. http://weblinks.westlaw.com/result/default.aspx?cnt=Document&db=CA%2DADC%2DTOC%3BRVADCCATOC&docname=22CAADCS60306&findtype=W&fn=%5Ftop&ifm=NotSet&pbc=4BF3FCBE&rlt=CLID%5FFQRLT4210523169193&rp=%2FSearch%2Fdefault%2Ewl&rs=WEBL10%2E02&service=Find&spa=CCR%2D1000&vr=2%2E0

(6) LennTech. "Water Treatment Solutions." Accessed March 2010. http://www.lenntech.com/library/ozone/cooling/ozone-applications-cooling-water.htm

(7) Zammit, Ken, interview between EPRI and Stanford University, March 19, 2010.

(8) Yarbrough, Mark. "Recycling, Reuse Define Future Plant Designs." Power. Accessed March 2010. http://www.powermag.com/issues/cover_stories/Recycling-reuse-define-future-plant-designs_562.html