IEAGHG Information Paper; 2013-IP22; Water Intensity of Power Generation

Background: *"Some technologies that minimize GHG emissions can be highly water-intensive, including power plants with carbon capture and storage (CCS), nuclear power plants, and certain types of concentrating solar power (CSP)" (World Bank 2013)*

Response:- The water consumption of power generation systems depends on a number of economic decisions made during the power station design based on the availability and cost of fresh water and site-specific issues at the time. If a fresh water supply is plentiful, then extensive use will be made of that resource to minimise cost. If the local supply of fresh water is constrained then design decisions can be made to reduce water consumption at modest cost.

Power stations commonly use a Rankine steam cycle in which water is used for two main purposes; make-up process water and cooling by water evaporation. When evaporative cooling is used, the power station water consumption for that purpose is an order of magnitude greater than the consumption of water for process purposes. Table 1 (Carter & Campbell 2009) provides a comparative picture of typical water intensities of conventional electricity generation technologies without constrained water supplies.

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,.

Alternatives to wet cooling of power stations via the evaporation of water are:-

- Rejection of heat to a large body of flowing water, such as a river or the ocean. Direct water cooling uses that body of water as a heat sink and although it is not a net consumer of that water at the power plant site, the resulting increased evaporation from a river can reduce water availability downstream;
- Air cooling, in which ambient air is blown over finned tubes. Air cooling typically reduces the efficiency of power generation by about one percentage point compared with evaporative cooling (IEAGHG 2010). Air cooling does not use water; and

- Hybrid cooling systems in which air cooling is integrated with evaporative cooling, which reduces the net water consumption.

Generation Process Water Requirements
Water is completely recirculated in the Rankine steam cycle. In practice impurities build up in that process water so some water is "blown down" from the circuit and replaced with very clean demineralised water. If clean water is available then it is usually cheaper to demineralise fresh water as make-up water and to dispose of contaminated water. However, blowdown water could be cleaned and demineralised and recycled as the make-up water, resulting in the conventional power station steam cycle being water-neutral.

Likewise, In the case of a CSP system, the steam cycle requires make-up water and produces wastewater. In an arid location where fresh water is produced by desalination, it would be economic to design a CSP power station to consume no fresh water. In that case the only other process water requirement would be for washing the mirrors, which might normally consume about 16 gal/MWh (USDOE 2008), but could potentially be more frugal.

In the case of CCS schemes, an amine scrubbing system is typically considered for post-combustion CO_2 capture. The aqueous amine solvent is recirculated with some losses and a need for demineralised make up water. Typically 44 kg of process water is required per tonne of CO_2 captured (IEAGHG 2012). For a coal fired power station with 90% CO_2 capture that corresponds to 10 gal/MWh. The net process water consumption could be reduced by integrated water management. The oxyfuel CCS scheme is a net producer of process water (IEAGHG 2010).

In nuclear power stations integrated water management systems aim to minimise all forms of discharge to the environment, so net process water consumption is small.

Water requirements for evaporative cooling
As shown in Table 1, evaporative cooling is a major net consumer of fresh water. If a plentiful supply of fresh water is not available at a potential power station site then an alternative waste heat rejection method must be identified at the initial design stage. If a large body of saline water is accessible then direct once-through cooling with seawater can be considered. If no large water supply is available then air cooling, with a consequent energy penalty, would need to be considered. In an arid location with a high daytime ambient temperature, which might be a good location for a CSP scheme, the energy penalty of air cooling would be increased because the back-end temperature of the Rankine steam cycle would not be as low as in a cold location. If a supply of saline water is available in such a location then it might be more energy efficient to consider producing clean water for an evaporative cooling system by using a reverse osmosis desalination plant, but the capital cost of such a scheme would be high.

In conventional parabolic power station cooling towers waste heat is mostly rejected as the latent heat of evaporated water, which is lost into the atmosphere. The water consumption for evaporative cooling is proportional to the energy loss, which depends on the thermal efficiency of power generation. Figure 1 shows the general relationship between power station efficiency and water intensity with some examples from a study of differing fossil fuel power generation systems (NETL 2007).

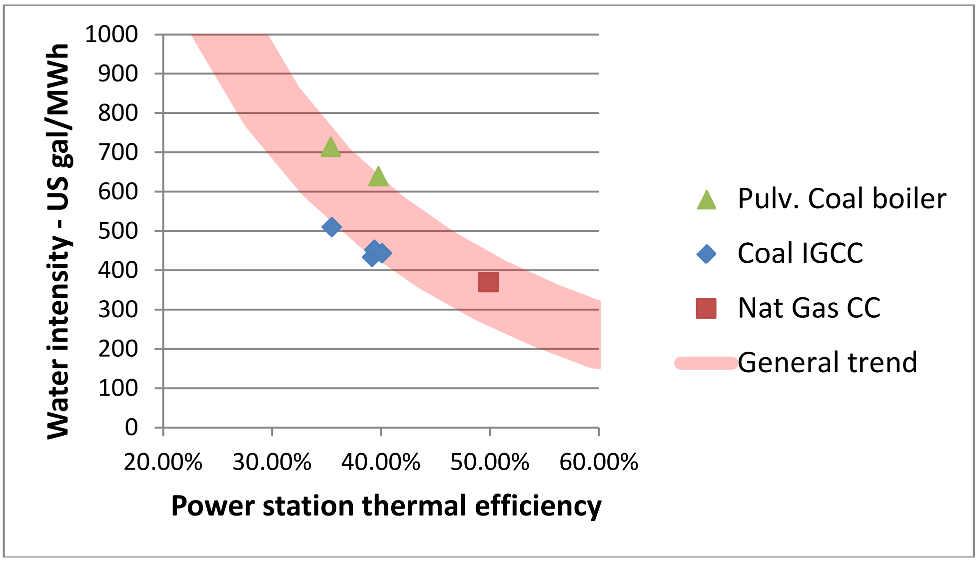

Figure 1. **Relationship between power station efficiency and water use intensity**

The thermal efficiency of a Rankine steam cycle depends principally on the temperature of the front-end steam input to the high pressure turbine. Advanced steam cycle designs aim to achieve as high a top temperature as material considerations will allow in order to maximise thermal efficiency.
In the case of CSP schemes the top temperature achievable depends on the design of the solar energy capture device. A solar tower CSP scheme can achieve a higher top temperature than a solar trough system, so a more thermally efficient Rankine steam cycle can be used. Accordingly the cooling requirement for a solar tower scheme would be less than for a solar trough system, as illustrated in Table 1.

In the case of a fossil fuel power plant with CCS there is an energy penalty arising principally from the use of low pressure steam for CO_2 capture, which would otherwise be able to generate electricity. In addition the CO_2 capture plant and CO_2 compression plant would consume some electricity. The overall thermal efficiency of a fossil fuel power plant might be reduced by about 15% to 20% due to the addition of CCS. The corresponding increase in cooling water requirement might be about 30% to 40% as illustrated in Figure 1.

In the case of a nuclear power station the top temperature of the Rankine steam cycle might be more constrained than in a fossil fuel power station hence the thermal energy conversion efficiency may be lower and the evaporative cooling water requirement somewhat higher as shown in Table. 1.
The very high water intensity of geothermal power generation reported in Table 1 reflects the relatively low temperatures that are typically available in geothermal fluids. The thermodynamic efficiency of the Rankine steam cycle is low in geothermal applications so the corresponding evaporative cooling water requirement would be high.

Conclusion
Power generation technologies that minimise GHG emission are generally less thermally efficient than conventional fossil fuel power plants, so require more cooling and hence more water if evaporative cooling is used. However, early design decisions can be made to reduce water consumption at modest cost.

References

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