MEMORANDUM

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TO: Paul Shriner and Jan Matuszko, EPA
FROM: John Sunda (SAIC) and Kelly Meadows
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SUBJECT: Cooling Tower Energy Penalties

EPA requested that Tetra Tech and SAIC document design assumptions used in developing the 316(b) cooling tower compliance costs. This memo clarifies the energy penalty of retrofit cooling towers.

Task: Clarify certain energy penalty assumptions, such as whether penalties at nuclear facilities would be higher than at coal facilities and whether EPA's costs include condenser replacement, where necessary. Review the assumptions used in the DOE and California once-through cooling policy and compare them to EPA's assumptions.

Background

The term "energy penalty" can be used in various contexts. Sometimes it refers only to the loss in energy production associated with lower turbine efficiency for retrofit facilities. Sometimes energy penalty also includes parasitic power consumption for fans and pumping. For the purposes of estimating compliance costs, both interpretations are included.

Energy penalty may also be expressed as the annual average or a maximum. The annual average energy penalty data is useful in determining overall annual costs, while the maximum energy penalty is used to estimate impacts on generating capacity for periods of peak demand during the warmer months. Using the maximum energy penalty to estimate annual cost would significantly overestimate the costs and using the average energy penalty to estimate the impacts on regional capacity would underestimate the impact.

Estimates of the energy penalty are generally based on the methodology used in the EPRI cooling tower worksheet. This involves estimating the energy penalty as two separate components: one for parasitic power consumption for fans and pumping expressed in MW; and one for turbine efficiency loss. A site-specific parasitic loss is calculated for each facility based on its flow; the national average is approximately 1.7 percent. Turbine efficiency varies by fuel type; nuclear plants operate at a higher pressure and would experience a higher loss of efficiency. The overall balance between fossil and nuclear (2.0) is consistent with the value used in EPRI's cooling tower cost estimation tool.

Table 1 presents a comparison of the EPA's estimated energy penalty for replacing once-through cooling with closed-cycle recirculating wet cooling towers along with values reported in other sources.

Table 1. Summary of Energy Penalty Data

Source	Maximum Total Energy Penalty (%)	Annual Average Penalty		
		Net Pump and Fan (%)	Turbine Efficiency (%)	Total (%)
EPA/EPRI – Fossil	NA	1.7[1]	1.5	3.2
EPA/EPRI – Nuclear	NA	1.7[1]	2.5	4.2
2002 Phase II proposed rule	1.4– 2.0	NA	NA	1.5 – 1.8
DOE Phase II[2]	2.4 – 4.0	NA	NA	0.8 – 1.5
DOE Nuclear[3]	Up to 5.8	NA	NA	2-3
California – Gas[4]	NA	1.0 – 2.0	0.8 – 1.3	2.0 – 3.2
California – Nuclear[4]	NA	1.4 – 2.6	2.9 – 3.6	5.0 - 5.5

[1] Fan and pumping energy is based on cooling water flow. The value of 1.7% shown in Table 1 for net fan and pump energy is a calculated average based on the average of the reported DIF flow divided by the steam capacity (707 gpm/MW). Estimated individual model facility-specific percent values will vary above and below this value.
[2]Source (DOE 2002). Adopted by EPA in Final Phase II Rule. Developed for coal-fired plants. Data is for condenser temperature range of 15^{o}F.
[3]DOE Study did not estimate nuclear penalty but cited a previous study of reported values (Veil 1992) with a range of 1% to 5.8% and estimated the annual average values would be in the 2% to 3% range. A subsequent DOE Study (DOE 2006) estimated nuclear penalty by increasing the coal-fired penalty by 25%.
[4] From California cooling water policy. Penalty was calculated for each facility using facility-supplied data. Data shown is for several selected examples.

The most recent estimates in Table 1 are from the technical and economic analysis supporting the proposed California Power Plant Once-Through Cooling Regulation.[1]

[1] California's Coastal Power Plants: Alternative Cooling System Analysis. February 2008.

This study includes a detailed estimation of the energy penalty associated with cooling tower retrofit for each electric generating facility in California. These analyses provide estimates for each facility and generating unit for the fan energy requirements, the net pumping energy requirements, and turbine efficiency reductions; all are expressed as a percent of power generation. Fan and pump energy values are conservative as they assume that fans and pumps will operate at full capacity year round. The turbine efficiency loss was calculated on a monthly basis using reported and estimated changes in generating unit heat rates.

Discussion:

Pump and Fan Energy

The California Report estimates for the pump and fan energy penalty component appear to be similar in magnitude to EPA's estimates and are based on basic engineering design principles. The DOE analysis includes pump and fan energy requirements as well, and examination of several examples shows that the fan and pump energy penalty component was around 0.8% at a condenser temperature range of 15°F. One important variable throughout these analyses is the condenser temperature rise (or range) which, for any given plant generating output, will affect the fan and pumping energy in relation to the generating capacity. This will affect the values shown in Table 1 which may not necessarily be based on the same design conditions. A lower condenser rise will result in higher recirculating flows and correspondingly higher energy requirements for fan and pumping requirements. The EPA method is not affected by this because it uses actual design intake flow values. The temperature ranges used in the California analysis were around 18 to 20°F.

Turbine Efficiency

As noted above, a different turbine efficiency penalty is used for fossil and nuclear facilities, reflecting the differences in operating pressures in the generating turbines. EPRI's methodology uses a 2% turbine efficiency loss for all facilities and is consistent with EPA's approach; the basis for EPRI's assumption is not stated in the documentation, but (based on our BPJ) is likely to be representative of the maximum value.

In California's analysis, average energy penalty estimates are also lower for the gas-fired plants and higher for the nuclear plants. A review of the methodology shows that the California estimates are based on several conservative assumptions and data selections. The approach values selected ranged from 12°F to 16°F, with the 16°F being for the nuclear plant with the highest turbine efficiency loss of 3.6%. These values are higher than the 10°F value used by and EPRI. The DOE report stated that "the typical commercial design is based on an approach….of 8 degrees plus 1-3 degrees to account for any plume recirculation."

All of the energy penalty methodologies presented in Table 1 calculated the annual average turbine penalty by averaging calculated monthly values. In the California analyses, each monthly value is based on the maximum wet bulb temperature for the month. The DOE analysis used the monthly average wet bulb temperature. The difference between the monthly maximum and average wet bulb temperature can be significant, and the use of monthly maximum values will skew the California numbers higher. Thus, it appears that the annual average turbine efficiency penalty values from the California analyses are somewhat overestimated.

Nuclear Facilities

In a 2008 report,[2] DOE estimated nuclear penalty values by assuming that nuclear penalties were 25% greater than those for fossil fuel plants. Similarly, a previous DOE study (DOE 2006) based fossil-fuel energy penalty estimates on the values reported in the 2002 DOE study and calculated the nuclear penalty by multiplying the coal-fired penalty by 25%.

The total average nuclear energy penalty of 4.2% used In EPA's cost analysis is approximately 30% higher than the non-nuclear penalty of 3.2% and thus is consistent with DOE estimates. EPA's nuclear penalty would still be lower than the California study estimates, but as noted above the California study estimates appear to be conservatively overestimated with respect to the annual average penalty.

Condenser Modifications

The California analysis assumed that condensers would require modification in the form of waterbox reinforcement and tube sheet bracing. This modification was included to account for the increase in water pressure associated with the need to pump water through the condenser to the top of the cooling towers. A conservative estimate of 5% of all direct costs was added to account for condenser modifications.

The EPRI worksheet instructions state: "The approach to a closed-cycle retrofit used in this analysis is the following: The existing once-through cooling system equipment is left intact to the extent possible; that is, the condenser, the circulating water pumps and the piping connections to the condenser inlet and exit waterboxes are kept the same." The EPRI methodology assumes that the retrofit configuration would be for the cooling tower water to be pumped from the condenser effluent channel through the towers to the intake pumps inlet using an additional set of pumps. In this configuration, there is no change to the condenser hydraulic conditions and thus no need to modify the condenser.

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[2] DOE. Electricity Reliability Impacts of a Mandatory Cooling Tower Rule for Existing Steam Generation Units. October 2008. Accessed at website: http://www.oe.energy.gov/DocumentsandMedia/Cooling_Tower_Report.pdf