MEMORANDUM

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FROM: John Sunda, SAIC and Kelly Meadows, Tetra Tech

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SUBJECT: Technology Analysis for the Discharge of Power Plant Combustion Flue Gas Through Natural Draft Cooling Towers

Tetra Tech and SAIC were tasked by EPA with reviewing the conceptual design of an emerging technology for managing air emissions: the discharge of treated power plant combustion flue gas by injection into the plume of a natural draft cooling tower. This design is an innovative technology, first introduced in 1981 in Europe that is just now being introduced in the United States. Normally, combustion flue gas is discharged and dispersed into the atmosphere through the use of tall smoke stacks. In this technology, a natural draft cooling tower (NDCT) serves the dual function of providing for discharge and dispersion of both the air pollutants contained in the flue gas and waste heat from the condensers. This technology is now a requirement for power plants in Germany (SPX 2010).

Background

In 2005, EPA issued the Clean Air Interstate Rule (CAIR) that requires reductions in sulfur dioxide (SO_2) emissions and nitrogen oxides (NOx) in 28 eastern US states by 2015. CAIR sets an emission reduction requirement for each State, based on capping power plant emissions collectively at levels that EPA believes are highly cost-effective to achieve. SO_2 annual caps are set at 3.6 million tons in 2010 and drop to 2.5 million tons in 2015. NOx annual caps are set at 1.5 million tons in 2009 and 1.3 million tons in

2015. CAIR was legally challenged and, on July 11, 2008, the US District Court of Appeals issued an opinion that remanded the rule, citing "more than several fatal flaws in the rule."

A subsequent December 23, 2008 ruling leaves CAIR and the CAIR Federal Implementation Plans (FIPs, including the CAIR trading programs) in place until EPA issues a new rule to replace CAIR in accordance with the July 11, 2008 decision. EPA informed the Court that development and finalization of a replacement rule could take about two years. The Court ruling did not modify any of the provisions in CAIR and the original deadlines are still effective. CAIR has increased the demand for the installation of equipment to remove SO_2 from flue gas in coal-fired power plants, and wet flue gas desulphurization (FGD) is the preferred method (Kelly 2007).

First Installation in US

The Cardinal Station power plant is a three unit coal-fired power plant located along the Ohio River in Brilliant, OH and is owned by AEP. Units 1 and 2 have generating capacities of 615 MW each and came online in 1967. Both use once-through cooling, withdrawing water from the Ohio River. Unit 3 has a generating capacity of 630 MW and first came online in 1977. Unit 3 uses a closed cycle cooling system with a 423 ft tall NDCT that was constructed as part of the original system. Recently, the plant has been required to upgrade its air pollution control equipment to include FGD on all three units, presumably in response to CAIR. An FGD upgrade has already been completed for Units 1 and 2 in 2006, with the treated flue gas being discharged through a single new stack that is >1,000 ft tall and lined with fiberglass reinforced plastic (FRP). Recently, the SPX Corporation was awarded a contract to design and install the first NDCT flue gas disposal system in the US on Unit 3.

Total costs for the Unit 3 SPX contract are $47 million and include a fiberglass reinforced plastic conduit for transporting the flue gas from the new FGD to the existing NDCT and modifications to the tower associated with the retrofit.[1] The SPX tower upgrade work was scheduled begin in late 2009 and the flue gas system installation is scheduled to be completed during the commissioning of a new FGD system in 2012. The following discussion examines the issues and benefits related to the use of NDCTs for the disposal of treated flue gas, especially as it relates to costs and cooling towers at power plants.

Technology Overview

Many of the flue gas treatment processes that are installed to meet more stringent air pollution discharge requirements (e.g., FGD) require that the flue gas be cooled in order

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[1] Cardinal is also demolishing and rebuilding the tower fill assembly to improve tower performance and to extend its life, but this work was not a requirement for the flue gas disposal project (SPX 2010a). NDCT upgrade work also includes adding a lining to the interior and outer surface of the tower near the top with a corrosion-resistant coating. This was performed by AEP during a plant shut-down last year in anticipation of this project and is not included in the SPX contract total.

to be processed, and many of these processes utilize wet scrubbing technology. In such processes, the flue gas is typically cooled to about 80 °C (176 °F) and becomes saturated with water vapor. The cooler flue gas introduces several problems within the air emissions control technology:

- It is saturated with water and still contains some SO_3, chlorides, and fluorides which can condense out as an acid and can be very corrosive, requiring expensive corrosion-resistant materials in all of the air pollution control and downstream equipment (fans, heat exchangers, ducts, stacks). The stacks and equipment must be designed to prevent condensed acid droplets from being emitted out the top of the stack.
- The existing stacks are typically designed and sized to use the buoyancy of hot gas to draw the gases up through the stack. The cooler flue gas will require reheat equipment and/or additional fan energy to transport the flue gas through the stack, both of which will require equipment with corrosion-resistant materials or linings.
- The reduced buoyancy changes the internal stack flue gas pressure from a negative to positive condition, increasing the likelihood that over time corrosive gases will pass through any cracks that may form in the stack liner and thus require the need for great care in design and installation of the flue liner.
- If not reheated, the colder flue gas plume exiting the stack will not rise as high, reducing the effective stack height and resulting in less effective dispersion of the plume. Thus, a taller stack may possibly be required if the air pollution controls do not compensate for the effect on ground level concentrations locally downwind.

The most common solution to these problems is to construct a new “wet” stack with a corrosion-resistant liner or lining. These stacks are designed with a lower gas velocity to minimize the emission of acid droplets out of the top of the stack. The use of the existing stack with modifications to resist corrosion plus the addition of gas reheat equipment is also an option. When installing a new FGD system, the use of an NDCT for flue gas disposal eliminates the costs of a new wet flue gas stack or the costs of modifying the existing stack system including reheat.

In the NDCT flue gas alternative, the cooled treated flue gas is piped from the air pollution control equipment and injected into the center of an NDCT well above the wet cooling section (at 49 meters height in one example). The cost of building a new smokestack system is replaced by the typically much lower cost of modifying the tower and installing the large diameter FRP conduit needed to transport the flue gas to the NDCT. Tower modifications include structural changes to accommodate the holes through the thin concrete shell needed for passage of the gases and measures required to deal with the presence of corrosive gases.

The introduction of the warmer (relative to water vapor from the cooling water stream) flue gas into the tower will provide additional buoyancy inside the tower, which in turn can increase tower air flow, providing some improvement to cooling tower performance. At the same time, the mixing and dispersion of the flue gas into the relatively large

NDCT plume allows better dispersion of the air pollutants than would occur using a conventional stack under most circumstances. One study stated that this flue gas disposal method should be effective in reducing local ground-level concentrations, since NDCT plumes are typically very buoyant with a densimetric Froude number[2] below 1 (Schatzmanna et al 1987). The reverse is true only under high wind conditions when the NDCT plume may be subject to tower and building downwash.

Benefits of the NDCT flue gas alternative include:

- Eliminated/reduced capital and O&M costs of treated flue gas discharge equipment downstream of the air pollution control equipment (stack, reheat equipment, fans).
- Improved cooling tower performance due to an increase in the volume of air entering the tower and passing through the wet cooling section, resulting from the increased buoyancy of air inside the NDCT. This would produce slightly colder cooling water leaving the tower, resulting in an improvement in turbine efficiency and plant heat rate.
- Improved dispersion of stack gases downwind under most conditions.

This technology is limited to NDCTs and cannot be implemented for mechanical draft towers (MDCTs). Cooled flue gases are still too hot to be of any use in cooling the condenser water, and the injection of treated flue gas into the air outlet of an MDCT would produce no benefit to the operation of the cooling tower. Such an application would result in unacceptable ground-level air pollution concentrations nearby, since MDCTs have a much lower discharge height and their plumes have a tendency to disperse near the ground and be recirculated.

Cost Considerations

EPA's 316(b) rule compliance cost estimates are based on mechanical draft towers. MDCTs have lower capital costs and higher O&M costs than NDCTs. According to a major cooling tower vendor, since NDCTs require a high capital investment, they are usually most economical when installed at large plants that operate frequently or continuously, such as a baseload coal or nuclear plant. When considering installation of a cooling tower, each individual facility would need to evaluate the balance between lower O&M costs of the NDCTs and their higher capital costs to determine the best option. For many plants, the expected service life for the NDCT needs to be about 40 or more years to reach the break-even point (SPX 2010b). However, when cost adjustments for components such as plume abatement are included in the comparison, or the savings of using an NDCT for treated flue gas versus installing a new wet stack are considered, then the break-even time frame can become much shorter.[3]

[2] The Froude number is a unitless measure that quantifies the resistance of floating objects.
[3] The degree to which the break-even point is reduced will vary depending on site-specific factors.

Brayton Point

As an example, the Brayton Point Power Plant is installing two 500 ft NDCTs with a total design flow of 720,000 gpm to meet 316(a) and (b) requirements. Information from the facility indicates that the two NDCTs will cost about $500 million ($700 per gpm), which is roughly 1.8 times greater than the cost predicted by EPRI's "difficult" retrofit costs estimate for a comparably sized conventional MDCT system ($280 million or $390 per gpm.

At first glance, the present value of the cost savings for O&M is $4 million[4] over 40 years, which at a 5% discount rate is about $70 million; this is not comparable to the roughly $220 million capital cost difference between the NDCT system and a comparably sized MDCT system. However, the EPRI "difficult" MDCT retrofit costs do not explicitly include plume abatement, which Brayton Point decided was necessary because of concerns about fog and icing on a nearby highway and bridge. Plume abatement towers cost between 2.5 and 3.5 times as much as conventional ones (SPX 2010a), assuming the tower component of an MDCT costs about $75 per gpm. Assuming that the 3.5x multiplier applies to saltwater systems, the plume abatement could add as much as about $260/gpm to the EPRI "difficult" MDCT retrofit cost. This additional $260/gpm is equivalent to $187 million, and the present value sum of all three costs ($280 + $187 + $70 million) is roughly $537 million for the MDCT option with plume abatement and including O&M. Thus, it appears that the need for plume abatement increased the cost of MDCTs to the point where the cost of each option was comparable. In addition, NDCTs have other favorable traits, such as being more reliable at resolving the safety issues of fog and ice and of producing higher net generating capacity during peak demand periods.

Cost Savings of NDCTs

Probably the largest cost saving item for the NDCT flue gas disposal option is the elimination of the cost of a new stack or modifications to the existing stack. New stacks will be required for all new generating units with conventional flue gas systems. For repowered and existing plants being retrofitted with flue gas treatment technology, the existing stack may not be suitable for continued use. Factors affecting the associated costs and the decision to build a new stack or modify the existing stack include:

- The condition and expected service life of the existing stack;
- The compatibility of the new flue gas conditions with the design of the existing stack;
- The modifications to the stack required, particularly with respect to the prevention of corrosion;
- The need for flue gas reheat equipment, equipment O&M, and added equipment and fan energy requirements; and

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[4] One major difference between these two tower options is that the NDCTs do not require fans; O&M cost savings for fan energy requirement should be about $3 to $4 million per year.

- The location of the existing stack with respect to the new pollution control equipment. A poor location could result in the need for an excessive length of costly conduit or in insufficient available space for placement of the conduit.

In many cases, retiring the old stack and building a new stack may be the selected option for a conventional flue gas system, as was the case for the original design at Units 1, 2, and 3 at Cardinal Station. In most cases, the option of using the existing stack has significant capital and much higher O&M costs and has generally been abandoned because of its high costs for little perceived benefit (Sargent & Lundy 2003).

A representative for a construction company that builds power plant stacks (who requested anonymity) estimated that a new stack for Unit 3 at the Cardinal Station plant would have cost about $10 to $15 million. This is equivalent to a unit cost of $15,400 to $23,100 per MW generating capacity for the 650 MW Unit 3. The reported new stack height for Units 1 and 2 is greater than 1,000 ft and it is assumed that the Unit 3 stack would have been comparable in height if that option had been chosen. The older original plant stacks for Units 2 and 3 are reported to be 826 ft and 895 ft, respectively.

As a way to verify these costs, SAIC recently managed a project involving the upgrading of the air pollution control equipment at the Iowa Army Ammunition Plant that included replacing the stack for a small coal-fired industrial boiler. The construction costs for this 150-ft tall stack were approximately $660,000, and the 257 MMBTU/hr boiler is estimated to be equivalent in energy output to a 27.8 MW coal-fired power plant based on an assumed heat rate of 9,300 BTU/hr. This is equivalent to a unit cost of about $24,000 per MW generating capacity which is similar to the high end estimate for the Cardinal plant's Unit 3. The fact that these two stacks of widely different heights have similar costs per MW is likely due to the fact that the economies of scale of the much greater flue gas volume (24X based on estimated equivalent generating capacity) are offset by the much greater height (6.7X) of the Cardinal Station power plant stack.

Stack height is determined using air dispersion modeling to identify the minimum height needed to meet local air pollution regulations. EPA has also established a "good engineering practices" (GEP) stack height for any given site-specific application which takes into consideration the downwash effects of nearby structures. The GEP stack height is the maximum height that can be used in air dispersion modeling estimates even if the actual stack is taller, and is intended to prevent the use of taller stacks instead of air pollution control equipment to meet air standards. The average height for coal-fired boiler stacks built between 1971 and 1976 was 570 ft (Bellas 2008). The average stack height for all stacks at plants reporting a coal-fired steam flow in the 2006 EIA database was 445 ft with the tallest being 1103 ft. At nearly 1,000 ft, the Cardinal Station stack heights and estimated costs appear to represent the higher end of the range of stack heights and thus costs for similar plants throughout the US.

Another important cost item is the cost of the treated flue gas conduit. The comparative lengths of conduit for each of the two treated flue gas disposal options will factor into the decision of which method will be selected. If the distance from the air pollution control equipment to the location of the NDCT is much greater than the distance to the existing or proposed stack location, then high conduit costs may favor use of a stack. Since stacks have a relatively small footprint, there is much greater flexibility in selecting a site for a stack than for an NDCT and so the distance to a new stack may tend to be shorter.

As a result of recent increases in the costs of corrosion-resistant metals, the trend has been to construct treated flue gas conduit using FRP, as will be the case for Cardinal Station Unit 3. One source estimated that installed FRP costs were about $100 to $150 per sq ft (Kelly 2008). Using $125 per sq ft, the estimated costs of the 290-ft diameter liner that carried the Unit 1 flue gas inside the new 954 ft stack at Cardinal station would be approximately $11 million. This is equivalent to approximately $14,000 per MW for a 1,000 ft length of flue gas conduit.

The case of Brayton Point provides additional perspective. While flue gas disposal may not have been an issue at Brayton Point, if it had been, the location of the two new NDCTs appears to be rather far at around 1,500 to 2,000 ft from the generating units. The resulting estimated cost for a conduit to the NDCTs of $21,000 to $28,000 per MW appears to be similar in magnitude to the cost of building a nearby new stack at $24,000 per MW. So in this case, had Brayton Point been required to upgrade their air pollution control equipment with FGD technology, the NDCT flue gas disposal option probably would not have resulted in any substantial cost savings.

Potential Implications for 316(b) and Other Regulations

EPA raised the question of whether the flue gas disposal technology should be included in the 316(b) economic analyses. As noted above, the decision to use MDCTs or NDCTs as a flow reduction technology is site-specific. The incorporation of FGD wastes into an NDCT may influence a facility's technology choice, but for the purposes of estimating national 316(b) compliance costs, MDCTs are the most appropriate technology given their versatility and the fact that they are the tower type that is most often utilized in cooling system retrofits and new construction. As noted above, for many plants, especially those with lower capacity utilization and shorter expected service life, using MDCTs may be the lower cost option as well. In some applications, MDCTs may be the more expensive option compared to NDCTs; in those cases, EPA's selection of MDCTs for cost estimation represents a conservative costing approach, as the higher cost technology is assumed for those facilities. In summary, given the limited applicability of the technology, it would not be appropriate to include consideration of flue gas disposal in the 316(b) rule economic analysis.

A second question would be whether a facility choosing to install NDCTs for compliance with 316(b) requirements should be included in any economic analyses for Clean Air Act (CAA) regulations. As stated above, the decision on which cooling tower technology to install incorporates a number of site-specific considerations that are not limited to solely the CAA regulations. However, it is reasonable to expect that some facilities may select NDCTs as a technology option for compliance with either or both regulations. Additionally, it is possible that facilities with existing NDCTS (like Cardinal) will take advantage of the cost savings versus construction of a stack for the FGD. As such, it would likely be appropriate for EPA to consider flue gas disposal in the context of rulemakings under the Clean Air Act.

For existing plants, one issue that may limit the applicability of this technology is that the timeline for compliance with air pollution requirements such as CAIR has already been established and decisions to install air pollution control equipment to meet the 2010 SO_2 caps have already been made. A facility may be able to amend its plans to incorporate an NDCT, but given the different time scales of CAA and 316(b) regulations, there may be minimal overlap in the decision-making criteria.

The technology may also be available to coal-fired generating units that will be newly constructed at an existing facility or for existing coal-fired generating units that are being repowered as coal-fired units, as long as the repowering requires major reconstruction or upgrade of the flue gas treatment and handling system. Repowered generating units that convert to cleaner burning fuels will tend to have less need for pollution control equipment and may require shorter stack heights.

Conclusion

As discussed above, the discharge of FGD emissions via an NDCT is an emerging technology that may be evaluated as an additional option for a facility or new unit that must implement closed-cycle cooling. Additionally, there may be some opportunities for compliance cost reductions by combining technologies to meet multiple water rules and air emissions regulations. At the present time, however, there is not enough information to forecast adoption and use of the technology.

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