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RE: Acid Gas Emissions and Coal-Fired Power Plants

This memorandum addresses acid gas hazardous air pollutants (HAPs) emitted by coal-fired electric utility boilers in relation to the Maximum Available Control Technology (Utility MACT) rules scheduled to be proposed by the U.S. Environmental Protection Agency (USEPA) by March 16, 2011. The acid gases hydrogen chloride (HCl) and hydrogen fluoride (HF) are considered; including their intrinsic hazards, emissions, impacts on the environment, control of emissions, and collateral benefits of their control. The Clean Air Act Amendments of 1990 identified more than 180 HAPs, including HCl and HF, which are known or suspected to cause adverse consequences to human health and the environment, making them subject to regulation under Section 112 of the Clean Air Act.

Acid Gases

Hydrogen chloride and hydrogen fluoride are strongly corrosive gases produced by coal-burning power plants. When combined with water, hydrogen chloride gas forms hydrochloric acid. The Agency for Toxic Substances and Disease Registry (ATSDR) characterizes hydrochloric acid as "corrosive and can cause irritation and burns" at high concentrations (ATSDR, 2010a). Similarly, for high exposures to HF, the Agency states that "hydrogen fluoride is irritating to the skin, eyes, and mucous membranes, and inhalation may cause respiratory irritation or hemorrhage" (ATSDR, 2010b). These effects occur at levels of exposure likely above what are generally encountered in outdoor air.

According to the USEPA National Emissions Inventory, 335,000 tons of hydrogen chloride and 45,000 tons of hydrogen fluoride are likely released each year by coal-burning power plants.

The amounts of hydrogen chloride and hydrogen fluoride produced by a particular power plant depend in large part on the concentrations of chloride and fluoride in the coal that is burned and whether any emission control systems are in use. Overall however, approximately 60% of the chloride and fluoride in coal burned in power plants is estimated to be released to the atmosphere as hydrogen chloride and hydrogen fluoride (USEPA, 1998a).

Coal-burning power plants are reported to be the largest anthropogenic source of hydrogen chloride and hydrogen fluoride emissions to air (USEPA, 2009a). Due to its high solubility in water, the majority of HCl is believed to be rapidly removed from the atmosphere by wet and dry deposition as well as by reactions with particles in the atmosphere (Sanhueza, 2001). Hydrogen fluoride is emitted as a gas or particle and can be adsorbed onto other particles (USEPA, 1998b). Hydrogen fluoride containing particles tend to remain suspended in the atmosphere longer than hydrogen chloride gas and can travel up to 500 kilometers or more as fine particles (USEPA, 1998b).

Because of their high solubility in water, acid gas vapors can readily react with the moisture/tissues in the upper airways. Likewise, water bound to microscopic particles can act as a "delivery system" for acids to the alveolar regions of the lung (USEPA, 1998b). Controlled exposures of people with asthma have shown irritation and restriction of the airways from exposure to hydrogen chloride (Fine, 1987). Other studies have shown both acids to irritate eyes, nasal passages and the lungs (USEPA, 2000a; USEPA, 2000b).

While the USEPA estimated that hydrogen chloride levels resulting from coal-fired power plant emissions are below published health-based guidance levels (USEPA, 1998a), the Agency states that it has "low confidence" in the guidance level (called a "reference concentration") due to limited study of this compound in human populations (USEPA 2000a). When combined with water, 100% of the hydrogen chloride dissociates and forms hydrochloric acid. For our purposes think of this complete dissociation as a characteristic of a "strong acid". Other "strong acids" in the atmosphere can result from emissions of nitrogen-based and sulfur-based gases released from coal-fired power plants (producing nitric acid and sulfuric acid, respectively). Strong acids or their precursors that are present in inhaled particles and gases have been linked with respiratory effects in large-scale epidemiological studies. A study of 13,000 children in 24 U.S. and Canadian cities found that strong acidity in particles was associated with increased episodes of bronchitis and reduced lung function and acid gases were associated with asthma

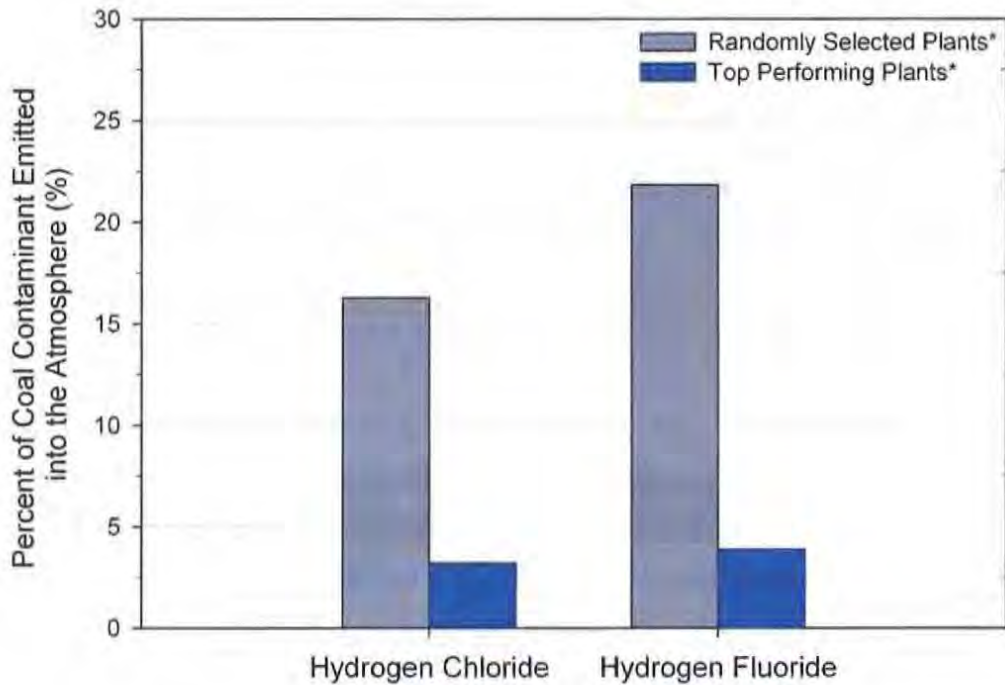
and related symptoms in children (Raizenne, 1996; Dockery, 1996). A more recent major children's study found also acid gases and particle pollution were associated with reduced lung function (Gauderman et al., 2004). The focus of these landmark studies on children is significant; as children are likely more vulnerable than a healthy adult to air pollution, including acidic gases and particles. Children have narrower airways, a faster breathing rate and tend to spend more time outdoors than adults, resulting in greater overall exposures (ATSDR, 2011; AAP, 2004). Results from these studies and other research (USEPA 1998a) show the potential harm from HCl vapor, particularly in the vicinity of coal burning power plants, where its contribution to acid aerosols and acidic precipitation has been not well-characterized.

Chloride released from hydrogen chloride can also significantly increase cloud acidity (USEPA, 1998b) and contribute to acid deposition over a regional scale. While much of the strong acidity has generally been thought to be related to sulfur dioxide and nitrogen oxide emissions, hydrogen chloride in particular likely plays a significant role in acid deposition in the vicinity of coal-burning power plants. Particularly within 15 kilometers of a power plant, USEPA has suggested that "...acidity in rainwater near a coal-fired power plant may be predominately the result of hydrogen chloride rather than sulfur dioxide or nitrogen oxides."

Acid gas emissions from power plants can also adversely impact ecosystems. A recent study in the United Kingdom attributed almost a third of the improvements from acid rain contamination since 1986 to reductions in hydrogen chloride from coal burning power plants (Evans, 2011). This is a much larger fraction than previously estimated. This study also showed that hydrogen chloride likely travels much further in the atmosphere than previously thought. Finally, this paper concludes: "Remarkably, [hydrogen chloride] has largely been overlooked in scientific assessments of ecosystem air pollution impacts."

Acid Gas Controls

Based on data gathered by the USEPA, control technologies for acid gases currently exist, are already in use by some power plants, and are effective at controlling acid gas emissions. (USEPA, 2009b; USEPA, 2009c). As shown in the chart below, hydrogen chloride and hydrogen fluoride emissions for a sample of better controlled coal-fired power plants were five times lower than emissions from a randomly selected set of coal-fired power plants.



*U.S. EPA (2009b, 2009c)

Coal, especially some bituminous coals can have significant chlorine content, which contributes to hydrogen chloride emissions when this type of coal is burned (Staudt 2010). Electric utility boilers that fire bituminous coal comprise roughly half of the coal-fired electric generating capacity of the U.S. Although many of these facilities are equipped with wet scrubbers that are highly efficient at capturing hydrogen chloride and other acid gases (e.g., hydrofluoric acid), a large number of bituminous fueled units are not equipped with scrubbers—having only particulate controls, and could require acid gas controls to meet emission limits set under the Utility MACT rules.

In order to meet the MACT standards for hydrogen chloride and hydrogen fluoride, some of the uncontrolled facilities may choose to install wet or dry scrubbers, also known as flue gas desulfurization. Wet scrubbers are more efficient at removing acid gases, but they are more costly than dry scrubbers. Modern wet scrubbers typically reduce sulfur dioxide emissions by about 98%¹; have higher capture rates for hydrogen chloride; and reduce emissions of sulfur

¹ 2009 EIA Form 860

trioxide and sulfate as well by about 50% or more. Reduction of sulfur trioxide and sulfate by wet scrubbers is supported by data in USEPA's Information Collection Request (USEPA 2009a; USEPA 2009b) on bituminous coal units equipped with an electrostatic precipitator (ESP). A review of these data showed significant reductions in condensable particulate emissions when comparing the average emissions of units with wet flue gas desulfurization versus those without it, as shown in Table 1. Condensable particulate matter consists of substances, such as many metals, that are a vapor in the hottest portions of an exhaust stack, but rapidly condense to form primary particulate matter (PM). These values are the results of relatively small data sets and may not be representative for all facilities, but they show a large reduction in condensable PM from the use of this technology.

Table 1 Comparison of Average Emission Rate of Condensable PM from ICR Data for Bituminous Coal Facilities With and Without Wet Flue Gas Desulfurization or "Scrubbers"			
Emission Rate, pounds per million British Thermal Units			
PM Control Device	Without Scrubbers	With Scrubbers	Percent Reduction
Electrostatic Precipitators	0.041*	0.009	78%
*This data included units with selective catalytic reduction, which would increase condensable PM somewhat, but typically not more than doubling it.			

Because of the cost of wet scrubbers (and to a lesser extent, dry scrubbers), other technologies are likely to be deployed for hydrogen chloride capture from unscrubbed bituminous coal fired boilers. Many unscrubbed facilities may install dry sorbent injection, which is much less expensive to install than a wet scrubber. Dry sorbent injection offers the ability to reduce both hydrogen chloride and sulfur oxides, but is generally less effective at removal of sulfur dioxide than the more costly wet or dry scrubbers.

At one facility hydrogen chloride and sulfur dioxide were removed using dry sorbent injection with both a baghouse (or fabric filter) and an ESP for particle collection (Davidson, 2010). This study showed that the unit with an ESP, the most commonly used PM control device on power plants, removed 95% of the hydrogen chloride and 50% of the sulfur dioxide. At the Mirant Potomac River Power Plant, equipped with dry sorbent injection and an ESP, roughly 98% of

hydrogen chloride and greater than 70% of sulfur dioxide were captured (Kong, 2008). A review of power plant data showed significant reductions in condensable PM emissions when comparing the average emissions of units with dry sorbent injection versus those without, as shown in Table 2 (USEPA 2009b; USEPA, 2009c). These values are the results of relatively small data sets and may not be representative for all facilities, but they show large reductions in condensable PM from the use of this technology.

Table 2 Comparison of Average Emission Rate of Condensable PM from ICR Data for Facilities With and Without Dry Sorbent Injection (DSI)			
Emission Rate, pounds per million British Thermal Units			
PM Control Device	Without DSI	With DSI	Percent Reduction
Electrostatic Precipitators**	0.041*	0.007	83%
Fabric Filters***	0.028*	0.003	91%
* This data included units with SCR, that would increase condensable PM somewhat, but typically not more than doubling it. ** Bituminous coal *** Powder River Basin coal			

Regardless of which control technology (scrubbers or dry sorbent injection) is selected, the anticipated MACT emission standards are expected to reduce aggregate emissions of HCl and HF from coal-fired power plants. Because of the physical and chemical properties of the available control technologies the measures taken to reduce HAP acid gases are also anticipated to lower emissions of condensable PM and sulfur dioxide. These collateral benefits are important because condensable PM and secondary PM formed from sulfur dioxide comprise the majority of fine particulate matter in most areas of the United States.

As described in the most recent comprehensive syntheses of the science, both short-term and long-term exposure to fine particulate matter has been found to cause cardiovascular effects, including mortality (USEPA 2009d; CASAC 2010). In addition, fine particle exposure has been found to be a likely cause of adverse respiratory effects, including increased visits to emergency departments and hospital admissions; worsening of respiratory symptoms; and reduced lung function (USEPA 2009d, CASAC 2010). Long-term exposure to fine particles has also been linked to reproductive and developmental effects, cancer, mutagenicity and genotoxicity

(USEPA 2009d). Fine particulate matter has negative impacts on the environment as well. For instance, sulfate-laden fine particulate matter is the key contributor to impairment of visibility in pristine areas such as National Parks (USEPA 2009d). For these reasons, public health and environmental benefits accrued from acid gas controls are expected to be substantial.

The potential value of collateral benefits from the Utility MACT Rule is indicated EPA's recent Regulatory Impact Analysis for MACT on industrial boilers (USEPA 2011a). In that analysis, EPA estimated that public health benefits of at least \$22 billion to \$54 billion would be achieved by MACT controls on industrial boilers. In comparison, the costs of controls were estimated to be \$1.4 billion. EPA attributed over 90% of the public health benefit to reductions in sulfur dioxide emissions, presumably achieved as a by-product of acid gas controls on those boilers. With a benefit-cost ratio of at least 16 to 1, the public health and economic value of controlling acid gas emissions from those boilers is clear. Although not quantified directly, technologies that control acid gas emissions may also reduce emissions of hazardous metals² like mercury and selenium, which are not as effectively controlled by conventional particle technologies. (USEPA, 2010).

While there has been some debate over whether collateral benefits can be considered in rulemaking for HAPs, EPA is expressly authorized by Congress to consider the collateral benefits of controlling sulfur dioxide and other criteria pollutants when establishing National Emission Standards for Hazardous Air Pollutants (Federal Register, 2010). This interpretation of the law was recently affirmed. After consideration of extensive public comments on this subject EPA concluded it knows of "no principle in law or common sense" that precludes the Agency from considering collateral environmental benefits when acting to regulate HAP emissions under the Clean Air Act (USEPA 2011b).

² As in some EPA materials, the class of pollutants referred to for simplicity here as 'metals' includes some elements (e.g. arsenic and selenium) that are not, strictly speaking, fully metallic.

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