INTEGRATED MACT COMPLIANCE PLANNING

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ABSTRACT

MACT compliance planning for electric generating units (EGU) is complicated by MACT-specific multi-pollutant regulations overlaid by other near-term emissions and ash regulations, and the availability of relatively low-cost natural gas. Significant configuration and performance information is available through the recent EGU MACT information collection request and results from recent technology demonstrations. This has been analyzed in the context of current and near-term emissions regulations and energy demand forecasts from sources such as EPRI and the EIA. This paper will provide a performance review of several coal and air pollution control combinations and retrofit options that meet cost and performance targets under a multi-pollutant regulatory landscape.

INTRODUCTION

On March 16 EPA proposed Mercury and Air Toxics Standards (MATS) for coal-fired electric power generating plants.[1] The rule was based upon the Maximum Achievable Control Technology (MACT) provisions of the Clean Air Act Amendments. The MACT process involved establishing emissions limitations on 187 listed HAPS based upon the average emissions of best performing 12% of plants. The proposed rule identified limits for mercury, HCl as a surrogate for all acid gases, and particulate matter as a surrogate for non-mercury metals. EPA has proposed SO_2 as an alternative surrogate for acid gases on units with scrubbers because scrubbers demonstrate effective removal of HCl. The rule is scheduled to be finalized by November 2011. Power plants will then have 36 months to specify and install control equipment to meet a compliance deadline of November 2014.

Planning for MATS compliance in combination with other regulations such as the Cross States Air Pollution Rule (CSAPR), which affects plants in from the Midwestern states and Texas through the Eastern US, as well as potential regulations affecting cooling water, ash, and greenhouse gas emissions will require significant effort by the industry to minimize risks of non-compliance while balancing the economics of retrofits compared to other options for electricity generation including replacing some coal units with low cost gas.

The most significant aspect of the planning effort is determining which plants may require the addition of large capital equipment, such as scrubbers and fabric filters, and which plants can achieve compliance with low-capital cost technology such as activated carbon injection (ACI) for mercury and dry sorbent injection (DSI) for SO_2, acid gases, and condensable particulate matter. According to EPA's Integrated Planning Module,[2] the capital cost of a wet scrubber exceeds $700/kW (2011). Dry scrubbers save roughly 15% of the costs of wet scrubbers, and the reported installation costs of DSI are estimated at 5% of wet scrubber costs. For plants that have already invested in scrubbers to control SO_2 emissions, which include more than 60% of the US fleet, control decisions typically focus on leveraging the initial investment to meet future regulations. For non-scrubbed plants, the decisions can be more complex due to uncertainties around future regulations unless the cost of modifications can be minimized to mitigate risks.

Several low capital cost technologies are being considered as options for either partial or full compliance with the proposed MATS. These include:

- Mercury control
  - Activated carbon injection (ACI)
  - Halogen-based coal additives to increase the fraction of oxidized mercury
  - Minimize SO_3, which can interfere with native mercury control and effectiveness of ACI
    - Replace SO_3 with alternate flue gas conditioning
    - Limit coal sulfur
    - Mitigate SO_3 with DSI

- HCl control
  - Dry sorbent injection
  - Reduced chlorine in coal

- Particulate
  - Optimize performance of existing system or upgrade equipment
  - Minimize SO_3 to control emissions of condensable particulate matter

UNIT WITH SCRUBBERS

Of the 316 GW of US coal-fired capacity, the DOE reports that 62% has already invested in wet or dry flue gas desulfurization units, or scrubbers.[3] EPA estimated that 66% have already installed SO_2 or NOx controls.[2] Since scrubbers represent the highest single capital investment for compliance, units that have already invested in a wet scrubber represent the lowest risk units for retirement because future retrofits represent lower incremental costs compared to plants that require scrubbers and other pollutant specific controls. For those units with scrubbers already in service, many in the CSAPR region have already invested in NOx controls such as selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR) to meet compliance requirements. SCRs represent another large capital investment that is included in the retrofit-or-retire equation.

Scrubber and SCRs are designed for SO_2 and NOx control, but affect controls for other emissions identified in the MATS. For example, as noted above, scrubbers have demonstrated effectiveness for HCl control and plants in compliance with SO_2 standards typically can achieve compliance with the proposed MATS HCl limits. In many cases, SCRs and scrubbers also contribute to mercury capture. Mercury present in the vapor phase is typically present either water-soluble oxidized mercury or insoluble elemental mercury. Units firing higher halogen coals, which includes most bituminous coals, or coals treated with a halogen-based coal additive, often demonstrate high fractions of oxidized mercury whereas units firing low halogen fuels including most western fuels have flue gas with primarily elemental mercury. SCR units installed to control NOx emissions are fairly effective at increasing the fraction of oxidized mercury when sufficient halogens are present in the flue gas because the catalyst converts some of the elemental mercury to a halogenated form of oxidized mercury such as $HgCl_2$. Scrubbers for SO_2 control are typically very effective at removing oxidized mercury. This is good news for many scrubbed plants, especially those with SCRs, because compliance-level mercury removal can often be achieved without adding mercury-specific controls.

Some Risks under MATS for Scrubbed Plants

Good news doesn't necessarily translate to zero risk, however, especially when multiple pollutants are included. The catalysts used in SCRs will convert a fraction of the incoming SO_2 to SO_3. For units firing higher sulfur coals or with high conversion catalysts, the SO_3 can pose balance-of-plant issues related to air preheater pluggage and downstream corrosion from acid deposition, as well as opacity issues as sulfuric acid aerosol forms a "blue plume" when it exits the stack. SO_3 is also a compliance concern. Limitations on condensable particulate matter were included in the proposed MATS, and sulfuric acid is a primary contributor to condensable particulate matter. Wet scrubbers are not effective at removing sulfuric acid aerosol. SO_3 also impacts the effectiveness of both unburned carbon and activated carbon to control mercury emissions. This is an issue for scrubbed plants that rely on some mercury control in the particulate collector, and may make compliance with mercury limits included in the MATS without adding SO_3 mitigation, such as DSI, to the pollution control strategy. DSI implementation is discussed in the next section.

Another risk for units with wet scrubbers is the potential for mercury re-emission. Some captured oxidized mercury can be reduced to elemental mercury in the scrubber solution. Elemental mercury has very low solubility, causing it to come out of solution and exit the scrubber with the flue gas. The chemistry of the wet scrubber is important: several factors can contribute to re-emission, and not all are well understood. Factors include the type of scrubber and the concentration of chlorine in the scrubber solution. Trace minerals can impact re-emission and there are indications that some DSI chemicals may influence scrubber chemistry enough to result in re-emissions. Several vendors are marketing chemicals and technologies to control re-emissions.

To consistently meet the MATS proposed mercury limits (1.2 lb/TBTU for non-lignite plants and 4 lb/TBtu for lignite plants), strategies to manage mercury in scrubbed units must be fully evaluated. Controls that can be employed upstream of wet scrubbers, or in conjunction with dry scrubbers, should be incorporated to minimize the risk of non-compliance and to allow flexibility in fuel choices.

Dry Sorbent Injection

Due to the high capital investment required for scrubbers, decisions regarding SO_2 and HCl control represent a hurdle that must be cleared prior to other retrofit decisions for plants that are currently unscrubbed. Technically, a wet or dry scrubber is a clear choice to reduce SO_2 emissions compared to other options such as DSI for units that are affected by SO_2 control regulations. However, economic factors are critical to the final choice of control technology. Of the more than 1100 generation units currently in operation, less than 50 firing bituminous or lignite coals and nominally 60 subbituminous plants are unscrubbed. Most of these bituminous and lignite plants are in CASPR states and owners are reviewing options to meet the upcoming SO_2 regulations. Approximately 65% of the unscrubbed bituminous units are less than 300 MW and have been in service for more than 40 years.[4] Because the incremental cost per kW of retrofitting emission control equipment is inversely proportional to the size of the plant, the capital breakeven point between retrofitting and replacing the power with other options such as low cost gas has many plant owners searching for lower capital options to mitigate a retirement decision. Significant capital cost savings can be realized where DSI can be effectively utilized to trim SO_2 and/or control HCl.

Choosing DSI for SO_2 may be an option some units to provide operating flexibility in the near term before compliance limits become stricter, but the choice must be carefully considered to manage overall levelized costs and risks. DSI for SO_2 control can require large sorbent feed rates, which correlate with increased operating costs. Injecting large amounts of material into the duct will impact the particulate loading to the particulate control device and, because the sorbents are alkaline, they impact the resistivity of the fly ash and the particulate collection efficiency for units with electrostatic precipitators (ESP). Both higher inlet particulate loading and reduced collection efficiency can increase particulate emissions, another pollutant category identified in the MATS. Increasing particulate emissions can also trigger a new source review.

Sodium-based sorbents have demonstrated effectiveness for SO_2 control and have been successfully used for decades at some plants. Removal as high as 80% is possible, but higher removal requires careful consideration of risks. These include increased particulate loading to the particulate collector and impacts on particulate control, as discussed previously. NO_2 has been shown to be produced by a secondary reaction, especially with high sorbent injection rates and when no NOx control is in place. NO_2, at sufficient concentrations, can result in an orange/brown plume and may interfere with mercury capture using ACI. Also, some jurisdictions limit the amount of sodium in fly ash due to leaching issues from landfills.

The addition of a fabric filter in conjunction with DSI, either as a replacement for an ESP or other particulate control device or in addition to an existing control device, can improve overall capture effectiveness for SO_2 and particulate matter. This, in conjunction with restricting fuel choices to limit sulfur, may provide an option for some plants to meet compliance requirements while managing costs significantly below estimated costs for a wet scrubber. With careful planning, the fabric filter could be designed to incorporate some new dry scrubber technologies to address more stringent control requirements in the future while managing both near and longer term expenditures. When a fabric filter is added downstream of an existing particulate collector, the bulk fly ash can be collected separately from spent sorbents, which can be beneficial depending on the sorbent type and use of the fly ash.

For plants in the western US and not included in CSAPR or subject to other SO_2 limits, the focus for scrubbing is to control HCl under the MATS. The proposed HCl limit is such that some units firing lower chlorine coals, such as PRB, could achieve compliance by managing fuel purchases instead of installing additional retrofit controls. Results from multiple full scale trials have led to the conclusion that DSI using alkaline sorbents such as hydrated lime, sodium bicarbonate and Trona, are viable acid gas mitigation control options and are well suited for a wide spectrum of utility and industrial applications. DSI used for HCl or SO_3 control requires much less sorbent and it is a promising option to control HCl for most sites firing low chlorine fuels, such as Powder River Basin subbituminous coal and some bituminous and lignite coals.

DSI has been in use for SO_3 mitigation for several years and the industry is gaining experience as more plants are requiring technology to control SO_3 produced in SCR systems. There are an estimated 60 DSI systems currently installed. Many existing DSI systems have demonstrated poor reliability and required significant maintenance to keep on-line. When choosing a DSI system to support compliance, careful consideration regarding the reliability of the design is critical due to the economic risks associated with non-compliance or lost generation resulting from Unit derates to maintain compliance. An example of a system designed to address maintenance issues and provide reliable operation is shown in Figure 1. To maintain compliance and cost competitiveness with other energy sources supplying our nation's electric grid, successful acid gas management systems will need to have low capital and operational costs, provide reliable operation, require limited manpower and equipment maintenance, and minimize balance of plant impacts.

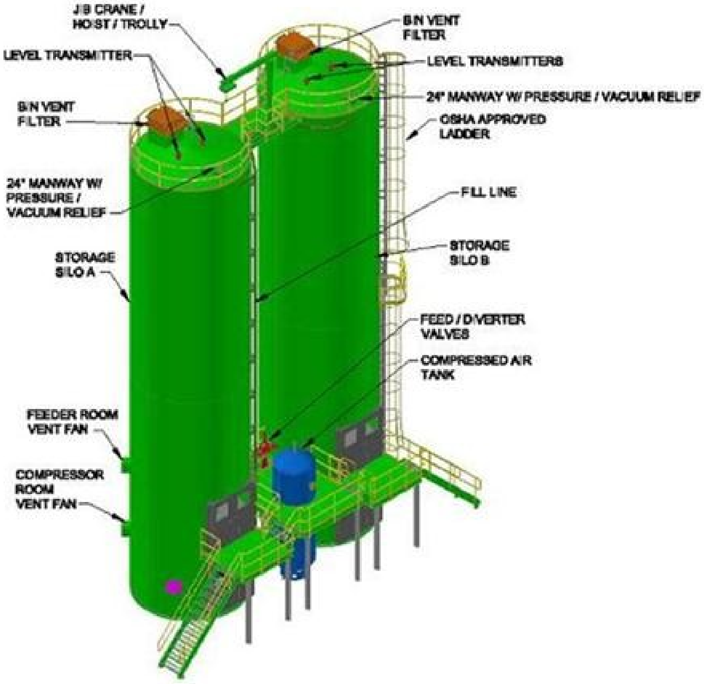

Figure 1. DSI system designed to provide reliable operation (© ADA-ES)

Both hydrated lime and sodium-based DSI are used to control SO_3. Materials can be injected either upstream or downstream of the plant's air preheater. Sorbent chemistry must be considered to minimize balance of plant impacts when determining the appropriate material, injection location, and injection rate. Most lime-based materials are not effective at controlling SO_2 unless special techniques are used. Because lime is not consumed by reactions with SO_2, it can be used to target SO_3 at lower usage rates than typically experienced with sodium-based materials. Sodium-based DSI has been demonstrated to be effective at controlling HCl. There is limited data available to determine the effectiveness of hydrated lime for HCl control. Confidential tests conducted by the authors suggest poor performance and some sources that claim the H_2O and CO_2 liberated from $Ca(OH)_2$ interfere with the formation of $CaCl_2$ [5].

ACTIVATED CARBON INJECTION

It was apparent early in the development process that mercury control for coal-fired power plants would not be a "one size fits all" technology. Many plants, especially those with low NOx burners and those firing bituminous coal, have some unburned carbon present in the fly ash, which can adsorb mercury and assist with overall mercury control. In many cases, the native carbon must be supplemented by activated carbon to achieve compliance-level mercury control. The effectiveness of carbon for mercury removal is dependent on several factors including the form of the unburned or activated carbon, the concentration of halogens and SO_3 in the gas, the fraction of oxidized mercury in the gas, and the temperature of the gas. Bituminous coals often contain sufficient chlorine to produce high fractions of oxidized mercury. Although SCRs convert more mercury to gas-phase oxidized forms, but also convert some SO_2 to SO_3, which can inhibit the effectiveness of unburned carbon for mercury adsorption.

ACI is a low capital cost technology that will be a key industry tool to reliably meet mercury emissions control limits. An example of the range of injection rates and removal effectiveness for activated carbon injection during multiple full-scale tests is presented in Figure 2 and in Table 1. A photo of a commercial ACI system is shown in Figure 3. For sites firing low halogen coal, a halogenated carbon is represented in the table and figure. In many cases, ACI can be used as a stand-alone technology for mercury control. In other cases, it must be applied in conjunction with other technologies. Consistently achieving the proposed MATS compliance level requires an understanding of factors that can impact the final emissions.

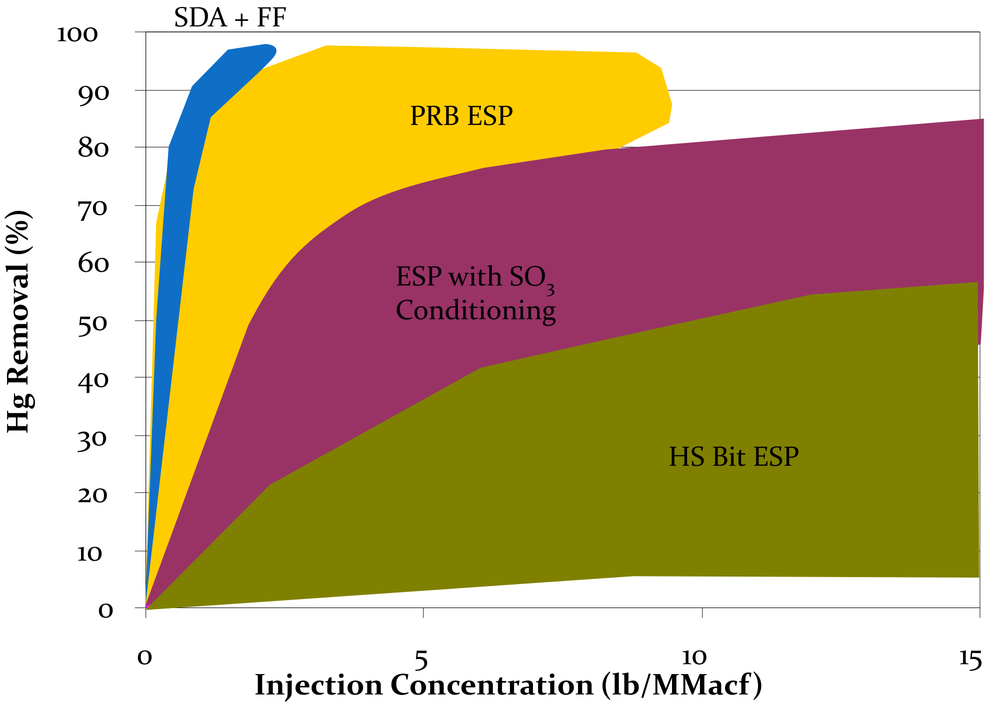

Figure 2. Summary of mercury control with activated carbon injection.

Table 1. Range of expected mercury control for various configurations.

Configuration	Range of AC for 90% Control (lb/MMacf)
PRB/SDA/FF	1 to 3
PRB/Toxecon	2 to 4
Bit/Toxecon	2 to 4
PRB/ESP	2 to not achieved
Bit/ESP	2.5 to not achieved

Figure 3. Example of a commercial ACI system (©ADA-ES 2010).

Based upon results from full-scale applications, the most important plant-specific factors that must be considered include:

- The presence of flue gas constituents such as SO_3. The elevated sulfur level at sites firing bituminous coals is one of the primary reasons that ACI is not as effective for these applications.

- Distribution. Mercury capture is enhanced by optimized sorbent distribution in the ductwork, particularly when the particulate control device is an ESP. This is affected by several factors including the injection grid design, access constraints that may limit the ability to install ports at the optimal location, mixing in the duct, the particle size of the sorbent, and the amount of conveying air used to enhance distribution.

- Sorbent/gas residence time. Mercury capture requires contact between the sorbent and flue gas. This is influenced by factors such as the duct design, the ability to inject well upstream of the particulate collection device, and the type of particulate collection device (electrostatic precipitator vs. fabric filter).

- Flue gas temperature. Mercury capture decreases at higher flue gas temperatures, whichare primarily determined by plant design and operating factors.

Activated carbon injection has been demonstrated to be very effective on sites firing western fuels, especially at plants where SO_3 concentrations in the duct are low. Across the U.S., approximately 25 GW of power is produced by units that both fire Powder River Basin (PRB) or low-sulfur bituminous coals and inject SO_3 to improve ESP performance. The injected SO_3 can detrimentally impact the effectiveness of ACI to achieve compliance mercury control[6]. An example of this impact at a plant using SO_3 injection is presented in Figure 4. The concentration of injected SO_3 was adjusted during the test period, as shown in the figure. When the SO_3 was turned off during a short-term test, the mercury removal was significantly higher. At injected SO_3 concentrations of 5 to 10 ppm, there is a significant impact on ACI performance for mercury control. Since SO_3 is used to enhance particulate removal in the plant's ESP, a replacement is necessary. An option is a non-SO_3-based flue gas conditioning chemical. Another option is adding a fabric filter downstream of the existing ESP, which is EPRI's TOXECON™ technology. TOXECON™ offers additional benefits including separating injected carbon from the bulk fly ash, providing additional particulate trim control, and providing an option to accommodate additional particulate loading associated with DSI for HCl control.

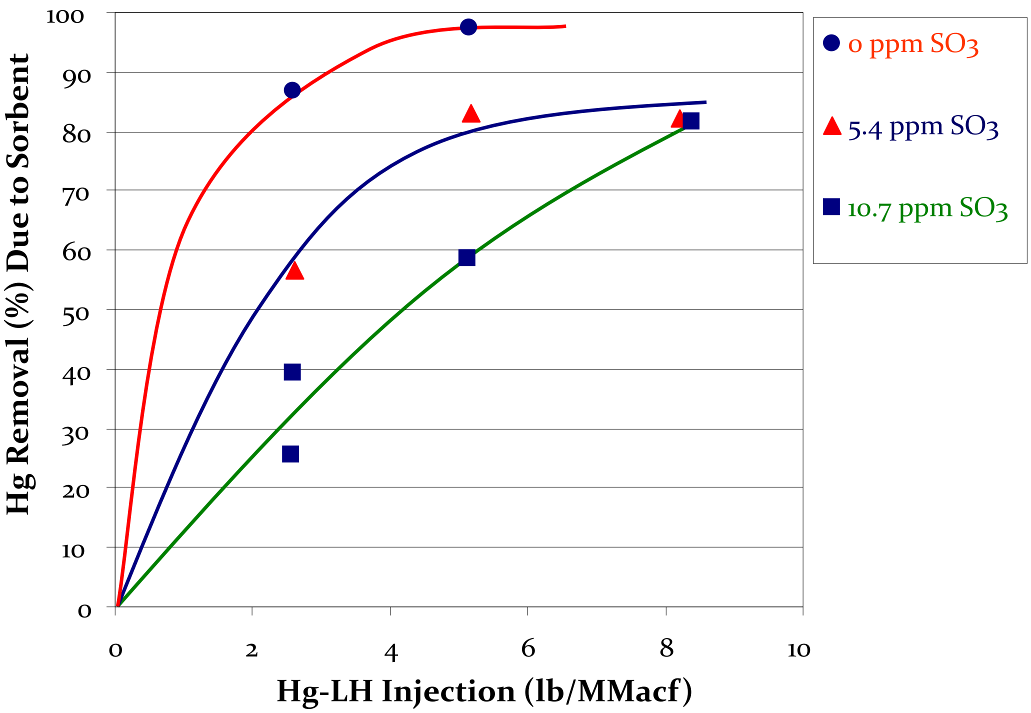

Figure 4. Impact of SO_3 conditioning on mercury control[6].

Sorbents treated with halogens can effectively remove > 90% of the mercury from sites firing western coals except under certain conditions.

ACI can also be successfully applied for mercury trim control on units firing bituminous coal is the SO_3 level is managed. For a unit firing 1.5% sulfur coal, nominally 10 ppm of SO_3 is produced from combustion. An SCR may increase the SO_3 to nearly 30 ppm, depending on the specifications of the catalyst. The first case may make achieving MATS compliance difficult without SO_3 mitigation. With 30 ppm SO_3, MATS compliance is unlikely. DSI is an option to mitigate SO_3 to a level where activated carbon is more effective. However, alkaline DSI sorbents require time in the gas to be effective requiring careful coordination between DSI and ACI to assure optimal performance. Because the additional particulate load from the DSI and ACI systems, as well as associated changes in flue gas chemistry can impact the performance of the particulate collection device, developing a complete compliance solution requires integrated compliance planning, as previously discussed.

PARTICULATE CONTROL

Strict particulate emissions limits proposed in the MATS may dominate retrofit decisions for many plants. EPA estimated that 243 fabric filters will be installed to meet the upcoming regulations (MATS proposed rule), at a cost of nominally half that of a wet scrubber.[2] Low capital options to support particulate compliance are limited. DSI can be effective at controlling SO_3, which contributes to condensable particulate matter. An alternate flue gas conditioning agent can be used to replace injected SO_3. Some benefit may be possible from ESP upgrades. However, many plant owners have already released requests for proposals to purchase fabric filters to meet proposed limits.

Summary of Low Capital Options to Meet MATS for Smaller Unscrubbed Units

Achieving MATS compliance with low capital options can be an effective approach for several plants. A summary of configurations and options is listed below.

- Units with hot-side ESP
  - No clear low capital options (mercury driver). A downstream fabric filter (TOXECON™) may be required.
- Units with cold-side ESPs
  - Fuel (low mercury, low sulfur, low HCl)
  - DSI as required to meet acid gas limits
  - Maximize ACI Effectiveness
    - Minimize SO_3 (DSI to mitigate or replacement FGC to limit additions)
- Options for HCl:
  - > 90% control required for most bituminous units. May require new scrubbers for some units.
  - < 80% control required for most plants with low-rank coals. Should be achievable with DSI or existing FGD for most plants.
- Options for Total PM
  - Limit is challenging for many plants due to condensable fraction
    - Minimize SO_3 (DSI to mitigate or replacement FGC to limit additions)
  - May result in several new fabric filters or ESP upgrades
- Options for Mercury
  - 80 to >90% control at the stack to meet proposed MATS emission limits required for most units
  - MATS limits achievable with ACI or ACI + coal additives on most subbituminous units if SO_3 FGC is eliminated
  - MATS limits may be challenging on units with higher sulfur coals and may require SO_3 mitigation
  - For units with SCRs: Low conversion SCR catalyst and minimize ammonia slip
  -

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