

# Comments on the Proposed Increase in the Minimum Emission Standard (MES) for Sulphur Dioxide (SO<sub>2</sub>) Applicable to Coal-Fired Power Plant Stacks in South Africa

by

Dr. Ranajit (Ron) Sahu, Consultant<sup>1</sup>



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## **I. Introduction**

I was requested by the Centre for Environmental Rights to critically assess the Department of Environmental Affairs's (DEA) proposal to modify the Minimum Emission Standard (MES) for sulphur dioxide (SO<sub>2</sub>), effective from 1 April 2020, increasing the limit from 500 milligrams per normal cubic meter (mg/Nm<sup>3</sup>) to 1000 mg/Nm<sup>3</sup>. Weakening (doubling) the MES limit for SO<sub>2</sub> would effectively allow coal-fired boilers to emit double their previously-allowed SO<sub>2</sub> pollution.<sup>2</sup>

As I elaborate below, it is my opinion that the MES should not be doubled to 1000 mg/Nm<sup>3</sup>, as proposed. Not only will this allow significantly more emissions and adverse harm to exposed populations, the proposal is premised upon assumptions that are false:

- that consumptive water use of the technology required to meet the lower (500 mg/Nm<sup>3</sup>) standard (flue gas desulfurization - FGD) is significant relative to its benefits;
- that the proposed alternative technology for meeting the relaxed standard of 1000 mg/Nm<sup>3</sup> (dry sorbent injection - DSI) is significantly cheaper; and
- that there are no adverse impacts to using DSI in quantities that would be necessary to achieve SO<sub>2</sub> reductions of around 70% as contemplated by the relaxed standard.

The reasons for my opinion are summarised as follows:

**FGD and water consumption:** There is no justification for doubling the MES to the proposed higher limit based on a broad-brush (i.e., without plant by plant assessment) indictment of FGD technology, simply by presuming that it has high consumptive water needs. Consumptive water needs of FGD are not large compared to other water uses in a power station if the thermal cycle relies on water cooling. And, focusing on just the water use by FGDs while minimising or not weighing the tremendous SO<sub>2</sub> reductions that they can achieve – 99% or more – is misleading and

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<sup>1</sup> Resume provided in Attachment A.

<sup>2</sup> See [https://www.environment.gov.za/sites/default/files/gazetted\\_notices/nemaqa39of2004\\_listofactivities\\_atmospheric\\_emissions.pdf](https://www.environment.gov.za/sites/default/files/gazetted_notices/nemaqa39of2004_listofactivities_atmospheric_emissions.pdf).

unbalanced. If, in some cases, even the small additional consumptive water needs of wet FGD plants would be problematic, dry-FGD designs can provide the requisite 85% reductions needed to achieve the 500 mg/Nm<sup>3</sup> MES. Dry-FGDs, while not as efficient as their wet counterparts, can still easily achieve reductions in the range of 90-95%.

**Impacts associated with Direct Sorbent Injection (DSI):** DSI was initially developed and is mostly applied in order to remove a range of acid gases such as hydrochloric acid (HCl), hydrofluoric acid (HF). Any SO<sub>2</sub> reductions were an ancillary co-benefit as a result. DSI was not developed to be a primary SO<sub>2</sub> reduction technology as the DEA media release suggests. The DSI process results will cause an increase in Particulate Matter (PM) emissions from electro-static precipitators (ESPs); will adversely affect ESP ash handling systems; cause increases in toxic mercury emissions; and result in adverse impacts from the disposal of ESP sorbent wastes. Mitigating these dramatically raises the costs of implementing DSI.

**Costs:** capital costs of FGD appear to be significantly inflated. Recent, mass application of FGD, in countries such as India (presently upgrading a large fraction of its coal-fired units with FGD) show that FGD capital costs can be significantly lower, if proper procurement strategies are followed. While capital costs for DSI are indeed lower than FGD, the operating costs (including costs to mine/produce the sorbent, transport it to the coal-plant, properly condition it including reducing its size to fine power by grinding, storing it onsite without exposing it to moisture, etc.) are sizeable, especially to achieve the presumed 70% SO<sub>2</sub> reduction. Based on this, and coupled with mitigating the adverse DSI impacts noted in the previous paragraph, government's expectation that DSI would be a much cheaper option than FGD is not only not unsupported, but is incorrect.

Instead, for coal-fired plants that intend to continue to operate in South Africa, I recommend that the 2020 stack MES should be reduced to levels in the range of 200 mg/Nm<sup>3</sup>, the norm in most other jurisdictions around the world, and a level that can readily and cost-effectively be achieved by implementation of FGD.

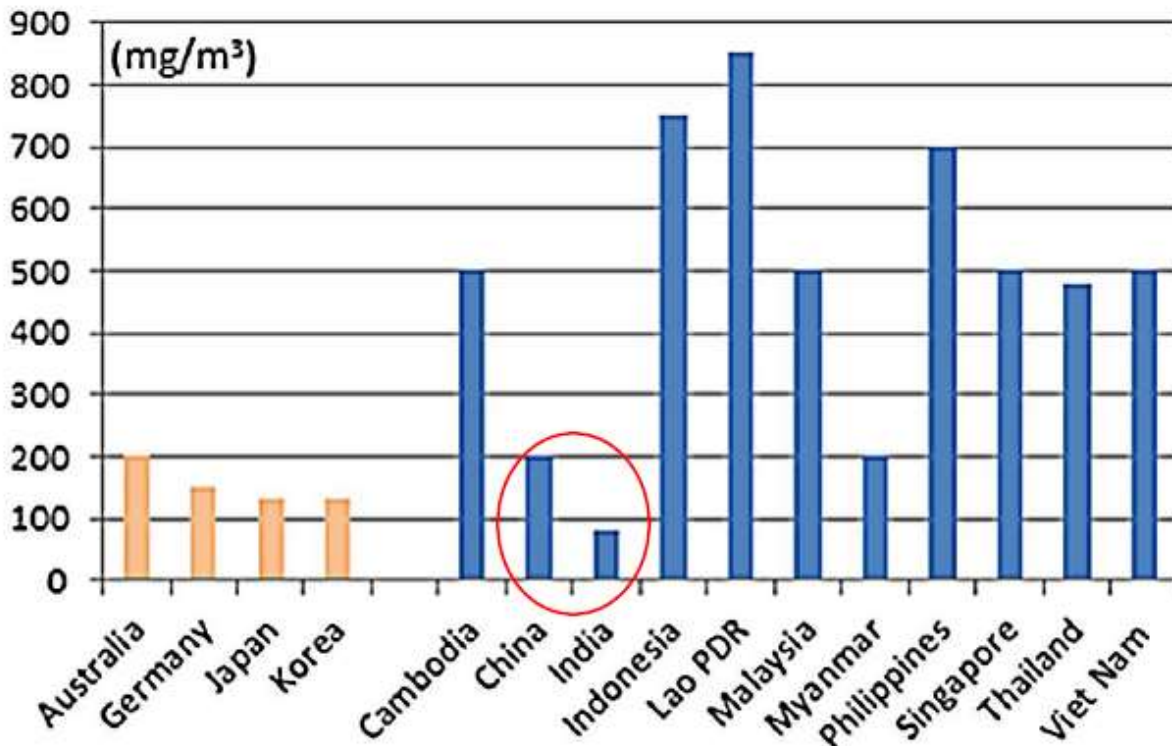
## **II. The Proposed 1000 mg/Nm<sup>3</sup> MES**

The April 2015 SO<sub>2</sub> MES applicable to existing coal-fired power plant stacks is 3500 mg/Nm<sup>3</sup>. This is an extraordinarily high level of allowable emissions of SO<sub>2</sub>, a known, major air pollutant<sup>3</sup> and is much higher than comparable allowable levels in other countries. See the chart below which shows SO<sub>2</sub> limits for coal-fired plants in various countries.<sup>4</sup>

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<sup>3</sup> Significant portions of South Africa's population are exposed to very high levels of SO<sub>2</sub>, including in so-called High Priority Areas (HPAs), where ambient levels of SO<sub>2</sub> (among other pollutants, including fine particulate matter, PM<sub>2.5</sub>, which is formed in the atmosphere from SO<sub>2</sub>) are known to be greater than health-based protective levels.

<sup>4</sup> Motokura, M., et. al., Improving Emission Regulation for Coal-Fired Power Plants in ASEAN, ERIA Research Project Report 2016, No. 2. Available at [http://www.eria.org/RPR\\_FY2016\\_02.pdf](http://www.eria.org/RPR_FY2016_02.pdf)



Standards that apply in the US pursuant to application of Best Available Control Technology (BACT) can be very low, on a case-by-case basis, even for existing plants when modified. As the chart above shows, developed countries as well as China and India have standards that are 200 mg/Nm<sup>3</sup> or less.

South Africa's current standard of 3500 mg/Nm<sup>3</sup> is simply off the charts. It was set to drop to 500 mg/Nm<sup>3</sup> in the coming years. While still not as low as levels in most other jurisdictions (i.e., excluding Laos, Malaysia, and the Philippines) as seen in the chart above, this would have represented a reduction of approximately 85% from the 3500 mg/Nm<sup>3</sup> level. Compliance with the 500 mg/Nm<sup>3</sup> level at existing plants was expected via use of flue gas desulfurization (FGD), a widely used group<sup>5</sup> of technologies to reduce SO<sub>2</sub> emissions from existing and new coal-fired power plants. FGDs, depending on design, can reduce stack SO<sub>2</sub> levels by 99% or greater.

In May 2019, the South African Minister of Environmental Affairs<sup>6</sup> requested public comments on a proposal to modify the April 2020 500 mg/Nm<sup>3</sup> stack limit for existing solid-fuel combustion

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See also, for example, Zhang, X., IEA Report on emission standards, available at <https://www.usea.org/sites/default/files/Emission%20standards%20and%20control%20of%20PM%202.5%20from%20coal%20fired%20power%20plant%20-ccc267.pdf>

<sup>5</sup> FGDs, generically, represent a set of technologies encompassing both wet and semi-wet or dry designs, with many variants depending on actual vendor designs.

<sup>6</sup> Now renamed as Department of Environment, Forestry and Fisheries

plants by increasing it to 1000 mg/Nm<sup>3</sup>. As justification and rationale, the government's statement media statement accompanying the proposal<sup>7</sup> notes the following.

“The intention of the amendment is to provide for existing plants to comply with a Sulphur dioxide (SO<sub>2</sub>) minimum emission limit of 1000mg/Nm<sup>3</sup> instead of 500mg/Nm<sup>3</sup>. This means that existing plants would reduce emissions from the current standard of 3500mg/Nm<sup>3</sup> to 1000mg/Nm<sup>3</sup>.

This is a significant reduction and would still lead to improvements in ambient air quality as total SO<sub>2</sub> emissions would be reduced by at least 50%. Currently, the State of Air Report over the years shows compliances with the SO<sub>2</sub> annual ambient air quality standard but government continues to regulate it because of its contribution to secondary pollution.

Achievement of the new plant standard of 500mg/Nm<sup>3</sup> for SO<sub>2</sub> requires the installation of limestone based wet Flue Gas Desulphurisation (FGD) which is the biggest cost driver in pollution abatement technology. This technology has the SO<sub>2</sub> removal efficiency of over 95 percent. Although FGD is efficient, there are challenges associated with it. The typical capital cost for a 4000MW power plant is R13 billion with an additional R3 billion operating cost per annum. These costs are very high for a slow growing fossil-fuel based economy.

Furthermore, FGD installation requires additional water resources and mining of new limestone as input material. South Africa's water resources are already constrained and cannot cope with the current and the growing demand from both domestic and industrial users.

Limestone would have to be mined because FGD uses good quality limestone to absorb SO<sub>2</sub> from the flue gas thus forming gypsum. The current market would not be able to absorb the gypsum that would be generated as such it would need to be disposed. The amount and quality of limestone needed is not readily available.

This means that new mines would be required and mining presents additional environmental problems. In addition, good quality limestone mines are located in the Northern Cape Province which is a considerable distance from the existing major sources of SO<sub>2</sub> and transportation would add to greenhouse gas emissions, amongst others. It should also be noted that the use of FGD technology in a plant generates additional CO<sub>2</sub> emissions, which is a priority pollutant in the Republic.

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<sup>7</sup> See Minister Nomvula Mokonyane intends to amend listed activities and associated minimum standards to improve air quality in South Africa (May 23, 2019), Available at [https://www.environment.gov.za/mediarelease/mokonyane\\_amendslegislationtoimproveairqualityinSA](https://www.environment.gov.za/mediarelease/mokonyane_amendslegislationtoimproveairqualityinSA).

I could not find a technical analysis or technical support document providing any additional detail beyond the media statement.

Revision of the new plant standard for the existing plants from 500mg/Nm<sup>3</sup> to 1000mg/Nm<sup>3</sup> opens up the scope for other technologies to be used in the abatement of SO<sub>2</sub> pollution and would not lead to as much CO<sub>2</sub> emissions. Dry Sorbent Injection (DSI), for example, is another type of FGD that does not require as much water. However, the SO<sub>2</sub> removal efficiency is between 50 and 60%. Although the efficiency is low compared to wet FGD, it has lower capital costs, which are not an impediment to retrofitting existing plants.”<sup>8</sup>

Setting aside the Orwellian media statement – i.e., touting the ‘improvements’ in air quality that would supposedly occur even while the proposal would allow *more* emissions of SO<sub>2</sub> – which is plainly impossible, much of the rationale provided above is not supported and rests on assumptions, which are either incorrect or simplistic. In this report, I address some of the Department of Environmental Affairs’ flawed statements or assumptions relating to SO<sub>2</sub> pollution controls (i.e., FGD and dry sorbent injection, DSI) in the above rationale, and identify important concerns that the government’s statements do not discuss. I understand that other specialists have addressed the increased emissions and consequent increased adverse health impacts that will result from the proposed relaxing of the already weak 500 mg/Nm<sup>3</sup> stack MES an even weaker 1000 mg/Nm<sup>3</sup> level, applicable to several of South Africa’s coal-fired power stations. Thus, I have not factored into my discussion below the additional harms of weakening the existing standard.

### **III. FGD and Water Consumption**

Although I agree with the Department of Environmental Affairs’ statement that the current MES of 500 mg/Nm<sup>3</sup> would require the use of FGD, the government does not recognize, given the 85% reduction that would be required (i.e., from 3500 mg/Nm<sup>3</sup> down to 500 mg/Nm<sup>3</sup>), that meeting the stricter standard can be achieved using not just wet FGD but also with semi-wet or dry FGD. As I discuss later, consumptive water use is not very high when using FGDs in most situations.

In any case, consumptive water use in FGDs is a very small fraction of the consumptive water used in a thermal power plant – especially those with water-based<sup>9</sup> thermal cooling cycles<sup>10</sup>, including once-through and evaporative cooling technologies. The schematic below (Figure 1) shows a

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<sup>8</sup> Media Statement, Minister of Environmental Affairs Intends to Amend Listed Activities and Associated Minimum Standards to Improve Air Quality in South Africa, 23 May 2019.

<sup>9</sup> Although some of the newer coal-fired units in South Africa use or are contemplating using air-cooling, most of them do not. It is my understanding that Units 5 and 6 at Grootvlei tested air-cooling and that units at Kendall are air-cooled. Units at Kusile, Majuba (some units), Matimba, and Medupi are/to be air-cooled.

<sup>10</sup> Cooling is an essential part of the thermal cycle used by coal-fired power plants to generate electricity. The thermal cycle requires that spent steam that leaves the turbine be condensed back to water, which then travels back to the boiler to be transformed to steam, which then comes back to the turbine – hence the cycle. The spent steam condensing process only works if its heat is rejected to another media – mostly water. In once-through cooling plants, this cooling water is drawn from a river or lake, or such and rejected back to the same waterbody in a hotter state. In some plants, cooling towers are used, in which heat is rejected via evaporating a portion of the water, which then cools the rest of the water – which is recirculated. Nonetheless the evaporated water must be “made-up” from a source like a river or lake, etc.

typical 500 MW subcritical power plant and its water needs, just as an illustration.<sup>11</sup> This plant uses evaporative cooling using a cooling tower. As seen, most of the consumptive use (the right side in the schematic) is dominated by the cooling water evaporation, followed by boiler blowdown, etc. Moisture lost as water vapor in the stack is also significant. Water leaving with gypsum, a product that is made using FGD sludge, is a miniscule fraction of the overall consumption, since much of the FGD water is internally recycled and reused as indicated in the figure.

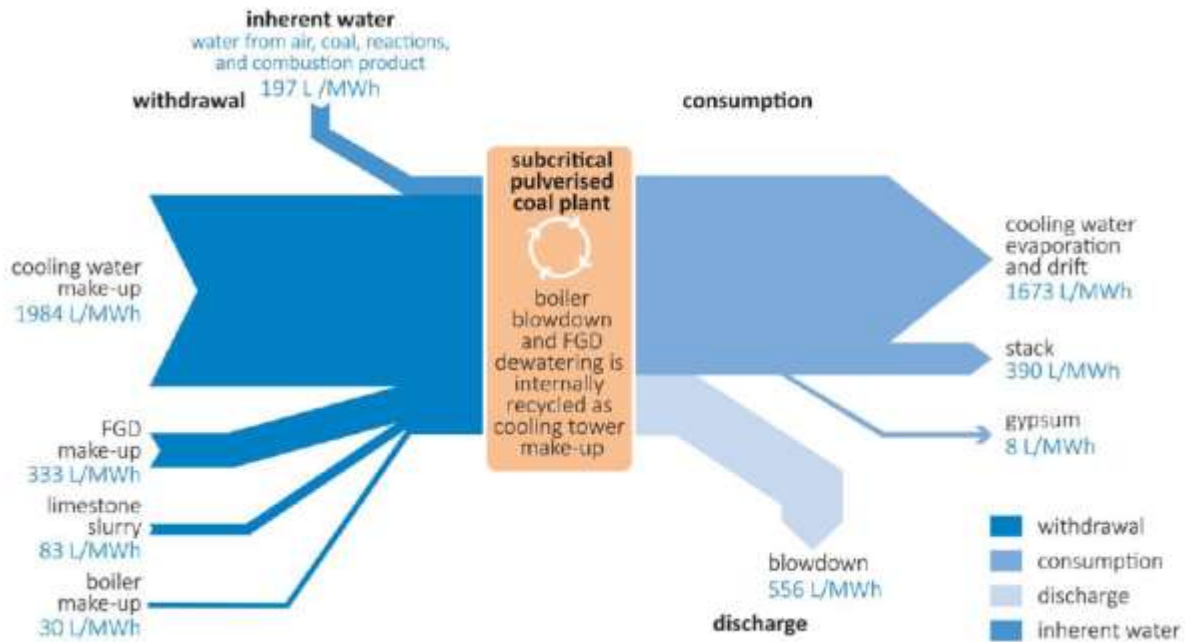


Figure 1: Water needs for a typical 500 MW subcritical coal-fired power plant

In other words, stating that water needs of FGD are large without putting it in the context of other consumptive water uses, on a plant by plant basis, is a misleadingly broad sweep. Compared to other consumptive water uses at a water-cooled thermal power plant, FGD water use is not large.

Additionally, focusing on just the water use by FGDs while minimizing or not weighing the tremendous SO<sub>2</sub> reductions that they can achieve – as noted earlier this can be 99% or more – i.e., much more than even the 95% level listed in the government’s media statement – is misleading and unbalanced.

<sup>11</sup> Carpenter, A. M., IEA report Water Consumption in Coal-Fired Power Plants, citing to others in the report. Available at <https://www.usea.org/sites/default/files/Water%20conservation%20in%20coal%20fired%20power%20plants%20-%20ccc275.pdf>

Lastly, as I have noted above, if in some cases the small additional consumptive water needs of wet FGD plants would be problematic, dry FGD designs can provide the requisite 85% reductions needed to achieve the 500 mg/Nm<sup>3</sup> MES. In dry-FGD, the slurry that contacts the exhaust gases evaporates to a dry solid powder trapping the SO<sub>2</sub> in the powder. Dry-FGDs, while not as efficient as their wet counterparts, can still easily achieve reductions around 95% and can achieve a limit of 200 mg/Nm<sup>3</sup>.

While plants in water stressed areas that use air cooling are beneficial<sup>12</sup> and can reduce consumptive water uses dramatically, it is my opinion that the air quality and associated health benefits resulting from the very large reductions in SO<sub>2</sub> emissions outweigh the relatively small additional consumptive water needs of FGD. There is no justification of doubling the MES to a dangerously high level based on a broad-brush indictment of FGD relatively little consumptive water needs.

#### **IV. Dry Sorbent Injection (DSI) and It's Impacts**

As the government's statement seems to suggest, one of the motivations of the proposed relaxing of the MES seems to be based on the belief that the 1000 mg/Nm<sup>3</sup> standard can be achieved by using DSI instead of FGD. DSI requires the injection of one or more types of "sorbents" in dry, finely-powdered form, into the exhaust or flue gas stream leaving the boiler of a coal-fired power plant. The choice of sorbent along with the unit's exhaust configuration will dictate where the injection should occur. The two primary DSI chemistries currently being used are based on calcium or sodium-based reagents. One of the more common calcium-based sorbents is calcium hydroxide. Sodium based sorbents include naturally occurring trona (sodium sesquicarbonate)<sup>13</sup> or synthetically manufactured sodium bicarbonate.

For more background information on DSI, please see the first 17 pages of a technical paper authored by me and provided in Attachment B. While the paper was created for assessing DSI applicability for a US coal-fired power plant, the introductory discussion regarding DSI and its implementation details provide useful context.

I discuss DSI in this section – in particular, focusing on aspects of this technology that are problematic in their application. For example, DSI was developed initially in order to remove a range of acid gases such as hydrochloric acid (HCl), hydrofluoric acid (HF), etc. SO<sub>2</sub> reductions were an ancillary co-benefit as a result. Here, the government suggests the use of DSI not as a co-benefit SO<sub>2</sub> reduction approach but rather a primary SO<sub>2</sub> reduction technology. I discuss below a few of the more important negative impacts of using DSI as a SO<sub>2</sub>-control approach that the Department of Environmental Affairs' statement above does not address. In addition, the

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<sup>12</sup> An even more admirable idea to further reduce water needs would be to look for electricity generation without using a thermal steam cycle, such as by using renewables. In this regard, the presumption, in the government's statement that South Africa is (and, by implication, will always be) a "slow growing fossil fuel based economy) seems puzzling.

<sup>13</sup> It is not clear that South Africa has significant deposits of trona unlike, for example, the US. Thus, if a sodium-based sorbent is used for DSI in South Africa, it would likely be sodium bicarbonate.

government makes a meritless cost argument relative to these technologies which I will discuss at the end of this section.

#### IV.1 Increased Emissions of Particulate Matter

As noted in the previous discussion, DSI involves the injection of solid, powdered reagents (the “sorber”) onto which gases such as HCl, HF, and SO<sub>2</sub> will adsorb,<sup>14</sup> thus removing them from the exhaust gases. The DSI reaction process creates a powder. This, along with any unreacted or unabsorbed sorber in the exhaust is collected in the downstream particulate matter (PM) control device. In the South African plants, this is typically an electrostatic precipitator (ESP).<sup>15</sup>

DSI will result in increased physical PM loading to the ESP. Very large quantities of DSI sorbers would be needed in order to reduce SO<sub>2</sub> emissions to the degree anticipated (i.e., from 3500 mg/Nm<sup>3</sup> down to 1000 mg/Nm<sup>3</sup> – i.e., around 70%). It is very rare that these sorts of SO<sub>2</sub> reduction levels are consistently achieved by DSI at all, since the main application of DSI is to reduce acid gases and not SO<sub>2</sub>. Nonetheless, if 70% reduction of SO<sub>2</sub> is intended, huge quantities of DSI sorbers would be needed. And, the ESP, instead of typically collecting just fly ash from the boiler, will now, with DSI injected upstream, be required to collect fly ash and a mixture of unreacted DSI sorbers and reaction powder. The physical load on the ESP will be far in excess of what it was designed for. To maintain any reasonable level of PM performance, many ESP upgrades would be needed. The Minister’s rationale does not discuss capital costs associated with such ESP upgrades, which would be far greater than the capital costs of the DSI itself.

Not only will physical loading to the ESP increase, the incoming mixture will have different chemical properties than the fly ash alone, for which the ESP was designed. This is because of the significant additional quantities of calcium and/or sodium that would be added via the DSI sorber. This will cause adverse implications on the functioning of the ESP system. PM capture in ESPs is a complicated function of many variables, including inlet particulate loading, the electrical resistivity of the particles, the concentration of sulfuric acid mist at the inlet of the ESP, as well as the changed concentration and changed particle size distributions if DSI sorbers are injected upstream of the ESP.

The electrical resistivity, in particular, is a very important parameter and ESPs are designed anticipating a range of expected electrical resistivities in the fly ash. Basically, the electrical resistivity of a particle determines how easy or difficult it will be for the particle to be electrically charged and to hold on to the charge. Without proper electrical charging, ESPs cannot remove particles from the waste exhaust gas stream. The degree to which resistivity will change depends on a quantity of DSI sorbers used. If DSI is used, as noted above, either calcium or sodium agents will be used. In general, calcium-based sorbers will increase the resistivity of the fly ash making the ash more difficult to charge and capture while sodium sorbers decrease the resistivity of the fly ash making the ash easier to charge and collect. Sulfur compounds such as sulfur trioxide

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<sup>14</sup> The acid gases HCl, HF, etc. are preferentially adsorbed in DSI sorbers, before SO<sub>2</sub> is adsorbed.

<sup>15</sup> ESPs, or more precisely dry ESPs are PM control devices which trap PM by first electrically charging PM particles as they enter the ESP, followed by collecting them on oppositely charged plates.



(which converts to sulfuric acid mist in the presence of water vapor always present in boiler exhaust gases) reduce resistivity making particles easier to charge and collect in ESPs. However, when DSI is used, the sorbents can preferentially adsorb sulfuric acid mist, removing it from the gas stream, and therefore adversely affecting PM control. While this discussion might indicate that there are benefits to using sodium-based sorbents, I will discuss other issues with sodium-based reagents below.

Both, the increased physical loading and its changed chemical composition, will have adverse impacts on the ESP's operation.<sup>16</sup> And, upgrading ESPs to accommodate the increased physical loading and its changes chemical composition is a significant cost. Depending on the current state of the ESP, this upgrading cost alone can range in the tens of millions of USD or hundreds of millions of SA Rand.

#### IV.2 Potential Ash Handling System Impacts

In addition to the ESP impacts noted above, there will be adverse impacts on the ESP's ash handling systems as well, since they will now be required to handle far greater quantities of ash as well as DSI reaction products and unreacted DSI sorbents. Thus hoppers, fans, blowers, ducts, etc. will all need to be re-evaluated and likely replaced. The capital costs for these replacements is not factored into the government's discussions.

#### IV.3 Adverse Impacts on Mercury Emissions

One of the more toxic byproducts of coal combustion is the emission of mercury and its compounds into the atmosphere. All coals contain mercury, in many forms, depending on the coal. Upon combustion, these mercury compounds are transformed and emitted into the atmosphere – typically as combination of elemental mercury, oxidized mercury (i.e., mercury chloride), and particulate-bound mercury. If an FGD is present, it removes substantial amounts of the oxidized mercury. DSI, however, by scavenging oxidizing agents such as chlorides, will adversely affect the formation of soluble oxidized mercury compounds and greater quantities of elemental mercury are likely to be emitted to the atmosphere.

#### IV.4 Adverse Impacts of Disposal of ESP Solids

As discussed in my paper in Attachment B, one of the more insidious adverse impacts of DSI use, particularly when using sodium-based sorbents, is the high leachability of toxic metals such as arsenic and selenium into groundwater, when spent DSI sorbents collected in the ESP are disposed-off in ash landfills or impoundments. These toxic metals then reach groundwater and affect all who rely on that groundwater, and can also migrate to nearby surface waters. Thus, if a power station does not have adequate mitigation to protect against contamination from its coal ash dump, the use of DSI will increase the potential risk.

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<sup>16</sup> I should also note that I have carefully reviewed ESP performance in many South Africa coal-fired power plants, as manifested in their reported PM emissions. Based on this it is my opinion that many of the ESPs at South Africa's coal-fired power plants are old and have significant deferred maintenance, resulting in poor PM collection performance. Adding more loading to these under-performing ESPs will simply make matters worse and will result in more PM emissions.

## **V. Costs**

The Department of Environmental Affairs' statement notes the high cost of FGD and the relatively lower capital cost of DSI. It is disingenuous, however.

First, the noted capital costs of FGD appear to be significantly inflated. Recent, mass application of FGD, in countries such as India (presently upgrading a large fraction of its coal-fired units with FGD) show that FGD capital costs can be significantly lower, if proper procurement strategies are followed.

Second, while capital costs for just DSI alone are indeed lower than capital costs of FGD, the operating costs of DSI (including costs to mine/produce the sorbent, transport it to the coal-plant, properly condition it including reducing its size to fine power by grinding, storing it onsite without exposing it to moisture, etc.) are sizeable, especially to achieve 70% SO<sub>2</sub> reduction. Operating costs also include disposal costs of the spent DSI/fly ash. And, as noted, significant capital costs would be needed for ESP upgrades. And, even more capital costs would need to be incurred to create proper disposal landfills in order to safely dispose of DSI (especially sodium-based) spent solids in order to avoid leaching of toxic metals into groundwater. Based on this, it is not clear that a levelized cost of DSI would be cheaper or significantly cheaper than FGD.

Based on this, it is my opinion that the government's expectation that DSI would be a much cheaper option than FGD is not only not unsupported, but is contrary to reality.

## **VI. Summary**

Based on the foregoing, it is my opinion that the MES should not be doubled to 1000 mg/Nm<sup>3</sup>, as proposed. Not only will this allow significantly more emissions and adverse harm to exposed populations, the proposal is premised upon assumptions that are false: that FGD consumptive water use is significant; that DSI is significantly cheaper; and that there are no adverse impacts to using DSI to achieve SO<sub>2</sub> reductions of around 70% as contemplated by the weaker proposed standard of 1000 mg/Nm<sup>3</sup>.

Instead, for coal-fired plants that intend to continue to operate in South Africa, I recommend that the 2020 stack MES should be reduced to levels in the range of 200 mg/Nm<sup>3</sup>, the norm in most other jurisdictions around the world, and a level that can readily and cost-effectively be achieved by implementation of FGD. This will result in the actual improvement of air pollution in South Africa, including in the various priority areas declared in terms of South Africa's air quality legislation.

## ATTACHMENT A – RESUME

**RANAJIT (RON) SAHU, Ph.D, QEP, CEM (Nevada)**

**CONSULTANT, ENVIRONMENTAL AND ENERGY ISSUES**

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### EXPERIENCE SUMMARY

Dr. Sahu has over twenty eight years of experience in the fields of environmental, mechanical, and chemical engineering including: program and project management services; design and specification of pollution control equipment for a wide range of emissions sources including stationary and mobile sources; soils and groundwater remediation including landfills as remedy; combustion engineering evaluations; energy studies; multimedia environmental regulatory compliance (involving statutes and regulations such as the Federal CAA and its Amendments, Clean Water Act, TSCA, RCRA, CERCLA, SARA, OSHA, NEPA as well as various related state statutes); transportation air quality impact analysis; multimedia compliance audits; multimedia permitting (including air quality NSR/PSD permitting, Title V permitting, NPDES permitting for industrial and storm water discharges, RCRA permitting, etc.), multimedia/multi-pathway human health risk assessments for toxics; air dispersion modeling; and regulatory strategy development and support including negotiation of consent agreements and orders.

He has over twenty five years of project management experience and has successfully managed and executed numerous projects in this time period. This includes basic and applied research projects, design projects, regulatory compliance projects, permitting projects, energy studies, risk assessment projects, and projects involving the communication of environmental data and information to the public.

He has provided consulting services to numerous private sector, public sector and public interest group clients. His major clients over the past twenty five years include various trade associations as well as individual companies such as steel mills, petroleum refineries, cement manufacturers, aerospace companies, power generation facilities, lawn and garden equipment manufacturers, spa manufacturers, chemical distribution facilities, and various entities in the public sector including EPA, the US Dept. of Justice, several states, various agencies such as the California DTSC, various municipalities, etc.). Dr. Sahu has performed projects in all 50 states, numerous local jurisdictions and internationally.

In addition to consulting, Dr. Sahu has taught numerous courses in several Southern California universities including UCLA (air pollution), UC Riverside (air pollution, process hazard analysis), and Loyola Marymount University (air pollution, risk assessment, hazardous waste management) for the past seventeen years. In this time period he has also taught at Caltech, his alma mater (various engineering courses), at the University of Southern California (air pollution controls) and at California State University, Fullerton (transportation and air quality).

Dr. Sahu has and continues to provide expert witness services in a number of environmental areas discussed above in both state and Federal courts as well as before administrative bodies (please see Annex A).

### EXPERIENCE RECORD

2000-present **Independent Consultant.** Providing a variety of private sector (industrial companies, land development companies, law firms, etc.) public sector (such as the US Department of Justice) and

public interest group clients with project management, air quality consulting, waste remediation and management consulting, as well as regulatory and engineering support consulting services.

- 1995-2000 Parsons ES, **Associate, Senior Project Manager and Department Manager for Air Quality/Geosciences/Hazardous Waste Groups**, Pasadena. Responsible for the management of a group of approximately 24 air quality and environmental professionals, 15 geoscience, and 10 hazardous waste professionals providing full-service consulting, project management, regulatory compliance and A/E design assistance in all areas.
- Parsons ES, **Manager for Air Source Testing Services**. Responsible for the management of 8 individuals in the area of air source testing and air regulatory permitting projects located in Bakersfield, California.
- 1992-1995 Engineering-Science, Inc. **Principal Engineer and Senior Project Manager** in the air quality department. Responsibilities included multimedia regulatory compliance and permitting (including hazardous and nuclear materials), air pollution engineering (emissions from stationary and mobile sources, control of criteria and air toxics, dispersion modeling, risk assessment, visibility analysis, odor analysis), supervisory functions and project management.
- 1990-1992 Engineering-Science, Inc. **Principal Engineer and Project Manager** in the air quality department. Responsibilities included permitting, tracking regulatory issues, technical analysis, and supervisory functions on numerous air, water, and hazardous waste projects. Responsibilities also include client and agency interfacing, project cost and schedule control, and reporting to internal and external upper management regarding project status.
- 1989-1990 Kinetics Technology International, Corp. **Development Engineer**. Involved in thermal engineering R&D and project work related to low-NO<sub>x</sub> ceramic radiant burners, fired heater NO<sub>x</sub> reduction, SCR design, and fired heater retrofitting.
- 1988-1989 Heat Transfer Research, Inc. **Research Engineer**. Involved in the design of fired heaters, heat exchangers, air coolers, and other non-fired equipment. Also did research in the area of heat exchanger tube vibrations.

## EDUCATION

- 1984-1988 Ph.D., Mechanical Engineering, California Institute of Technology (Caltech), Pasadena, CA.
- 1984 M. S., Mechanical Engineering, Caltech, Pasadena, CA.
- 1978-1983 B. Tech (Honors), Mechanical Engineering, Indian Institute of Technology (IIT) Kharagpur, India

## TEACHING EXPERIENCE

### Caltech

- "Thermodynamics," Teaching Assistant, California Institute of Technology, 1983, 1987.
- "Air Pollution Control," Teaching Assistant, California Institute of Technology, 1985.
- "Caltech Secondary and High School Saturday Program," - taught various mathematics (algebra through calculus) and science (physics and chemistry) courses to high school students, 1983-1989.
- "Heat Transfer," - taught this course in the Fall and Winter terms of 1994-1995 in the Division of Engineering and Applied Science.
- "Thermodynamics and Heat Transfer," Fall and Winter Terms of 1996-1997.

### U.C. Riverside, Extension

- "Toxic and Hazardous Air Contaminants," University of California Extension Program, Riverside, California. Various years since 1992.

"Prevention and Management of Accidental Air Emissions," University of California Extension Program, Riverside, California. Various years since 1992.

"Air Pollution Control Systems and Strategies," University of California Extension Program, Riverside, California, Summer 1992-93, Summer 1993-1994.

"Air Pollution Calculations," University of California Extension Program, Riverside, California, Fall 1993-94, Winter 1993-94, Fall 1994-95.

"Process Safety Management," University of California Extension Program, Riverside, California. Various years since 1992-2010.

"Process Safety Management," University of California Extension Program, Riverside, California, at SCAQMD, Spring 1993-94.

"Advanced Hazard Analysis - A Special Course for LEPCs," University of California Extension Program, Riverside, California, taught at San Diego, California, Spring 1993-1994.

"Advanced Hazardous Waste Management" University of California Extension Program, Riverside, California. 2005.

#### Loyola Marymount University

"Fundamentals of Air Pollution - Regulations, Controls and Engineering," Loyola Marymount University, Dept. of Civil Engineering. Various years since 1993.

"Air Pollution Control," Loyola Marymount University, Dept. of Civil Engineering, Fall 1994.

"Environmental Risk Assessment," Loyola Marymount University, Dept. of Civil Engineering. Various years since 1998.

"Hazardous Waste Remediation" Loyola Marymount University, Dept. of Civil Engineering. Various years since 2006.

#### University of Southern California

"Air Pollution Controls," University of Southern California, Dept. of Civil Engineering, Fall 1993, Fall 1994.

"Air Pollution Fundamentals," University of Southern California, Dept. of Civil Engineering, Winter 1994.

#### University of California, Los Angeles

"Air Pollution Fundamentals," University of California, Los Angeles, Dept. of Civil and Environmental Engineering, Spring 1994, Spring 1999, Spring 2000, Spring 2003, Spring 2006, Spring 2007, Spring 2008, Spring 2009.

#### International Programs

"Environmental Planning and Management," 5 week program for visiting Chinese delegation, 1994.

"Environmental Planning and Management," 1 day program for visiting Russian delegation, 1995.

"Air Pollution Planning and Management," IEP, UCR, Spring 1996.

"Environmental Issues and Air Pollution," IEP, UCR, October 1996.

### **PROFESSIONAL AFFILIATIONS AND HONORS**

President of India Gold Medal, IIT Kharagpur, India, 1983.

Member of the Alternatives Assessment Committee of the Grand Canyon Visibility Transport Commission, established by the Clean Air Act Amendments of 1990, 1992-present.

American Society of Mechanical Engineers: Los Angeles Section Executive Committee, Heat Transfer Division, and Fuels and Combustion Technology Division, 1987-present.

Air and Waste Management Association, West Coast Section, 1989-present.

#### **PROFESSIONAL CERTIFICATIONS**

EIT, California (#XE088305), 1993.

REA I, California (#07438), 2000.

Certified Permitting Professional, South Coast AQMD (#C8320), since 1993.

QEP, Institute of Professional Environmental Practice, since 2000.

CEM, State of Nevada (#EM-1699). Expiration 10/07/2017.

#### **PUBLICATIONS (PARTIAL LIST)**

"Physical Properties and Oxidation Rates of Chars from Bituminous Coals," with Y.A. Levendis, R.C. Flagan and G.R. Gavalas, *Fuel*, **67**, 275-283 (1988).

"Char Combustion: Measurement and Analysis of Particle Temperature Histories," with R.C. Flagan, G.R. Gavalas and P.S. Northrop, *Comb. Sci. Tech.* **60**, 215-230 (1988).

"On the Combustion of Bituminous Coal Chars," PhD Thesis, California Institute of Technology (1988).

"Optical Pyrometry: A Powerful Tool for Coal Combustion Diagnostics," *J. Coal Quality*, **8**, 17-22 (1989).

"Post-Ignition Transients in the Combustion of Single Char Particles," with Y.A. Levendis, R.C. Flagan and G.R. Gavalas, *Fuel*, **68**, 849-855 (1989).

"A Model for Single Particle Combustion of Bituminous Coal Char." Proc. ASME National Heat Transfer Conference, Philadelphia, **HTD-Vol. 106**, 505-513 (1989).

"Discrete Simulation of Cenospheric Coal-Char Combustion," with R.C. Flagan and G.R. Gavalas, *Combust. Flame*, **77**, 337-346 (1989).

"Particle Measurements in Coal Combustion," with R.C. Flagan, in "**Combustion Measurements**" (ed. N. Chigier), Hemisphere Publishing Corp. (1991).

"Cross Linking in Pore Structures and Its Effect on Reactivity," with G.R. Gavalas in preparation.

"Natural Frequencies and Mode Shapes of Straight Tubes," Proprietary Report for Heat Transfer Research Institute, Alhambra, CA (1990).

"Optimal Tube Layouts for Kamui SL-Series Exchangers," with K. Ishihara, Proprietary Report for Kamui Company Limited, Tokyo, Japan (1990).

"HTRI Process Heater Conceptual Design," Proprietary Report for Heat Transfer Research Institute, Alhambra, CA (1990).

"Asymptotic Theory of Transonic Wind Tunnel Wall Interference," with N.D. Malmuth and others, Arnold Engineering Development Center, Air Force Systems Command, USAF (1990).

"Gas Radiation in a Fired Heater Convection Section," Proprietary Report for Heat Transfer Research Institute, College Station, TX (1990).

"Heat Transfer and Pressure Drop in NTIW Heat Exchangers," Proprietary Report for Heat Transfer Research Institute, College Station, TX (1991).

"NO<sub>x</sub> Control and Thermal Design," Thermal Engineering Tech Briefs, (1994).

"From Purchase of Landmark Environmental Insurance to Remediation: Case Study in Henderson, Nevada," with Robin E. Bain and Jill Quillin, presented at the AQMA Annual Meeting, Florida, 2001.

“The Jones Act Contribution to Global Warming, Acid Rain and Toxic Air Contaminants,” with Charles W. Botsford, presented at the AQMA Annual Meeting, Florida, 2001.

**PRESENTATIONS (PARTIAL LIST)**

"Pore Structure and Combustion Kinetics - Interpretation of Single Particle Temperature-Time Histories," with P.S. Northrop, R.C. Flagan and G.R. Gavalas, presented at the AIChE Annual Meeting, New York (1987).

"Measurement of Temperature-Time Histories of Burning Single Coal Char Particles," with R.C. Flagan, presented at the American Flame Research Committee Fall International Symposium, Pittsburgh, (1988).

"Physical Characterization of a Cenospheric Coal Char Burned at High Temperatures," with R.C. Flagan and G.R. Gavalas, presented at the Fall Meeting of the Western States Section of the Combustion Institute, Laguna Beach, California (1988).

"Control of Nitrogen Oxide Emissions in Gas Fired Heaters - The Retrofit Experience," with G. P. Croce and R. Patel, presented at the International Conference on Environmental Control of Combustion Processes (Jointly sponsored by the American Flame Research Committee and the Japan Flame Research Committee), Honolulu, Hawaii (1991).

"Air Toxics - Past, Present and the Future," presented at the Joint AIChE/AAEE Breakfast Meeting at the AIChE 1991 Annual Meeting, Los Angeles, California, November 17-22 (1991).

"Air Toxics Emissions and Risk Impacts from Automobiles Using Reformulated Gasolines," presented at the Third Annual Current Issues in Air Toxics Conference, Sacramento, California, November 9-10 (1992).

"Air Toxics from Mobile Sources," presented at the Environmental Health Sciences (ESE) Seminar Series, UCLA, Los Angeles, California, November 12, (1992).

"Kilns, Ovens, and Dryers - Present and Future," presented at the Gas Company Air Quality Permit Assistance Seminar, Industry Hills Sheraton, California, November 20, (1992).

"The Design and Implementation of Vehicle Scrapping Programs," presented at the 86th Annual Meeting of the Air and Waste Management Association, Denver, Colorado, June 12, 1993.

"Air Quality Planning and Control in Beijing, China," presented at the 87th Annual Meeting of the Air and Waste Management Association, Cincinnati, Ohio, June 19-24, 1994.

## Annex A

### Expert Litigation Support

#### A. Occasions where Dr. Sahu has provided Written or Oral testimony before Congress:

1. In July 2012, provided expert written and oral testimony to the House Subcommittee on Energy and the Environment, Committee on Science, Space, and Technology at a Hearing entitled “Hitting the Ethanol Blend Wall – Examining the Science on E15.”

#### B. Matters for which Dr. Sahu has provided affidavits and expert reports include:

2. Affidavit for Rocky Mountain Steel Mills, Inc. located in Pueblo Colorado – dealing with the technical uncertainties associated with night-time opacity measurements in general and at this steel mini-mill.
3. Expert reports and depositions (2/28/2002 and 3/1/2002; 12/2/2003 and 12/3/2003; 5/24/2004) on behalf of the United States in connection with the Ohio Edison NSR Cases. *United States, et al. v. Ohio Edison Co., et al.*, C2-99-1181 (Southern District of Ohio).
4. Expert reports and depositions (5/23/2002 and 5/24/2002) on behalf of the United States in connection with the Illinois Power NSR Case. *United States v. Illinois Power Co., et al.*, 99-833-MJR (Southern District of Illinois).
5. Expert reports and depositions (11/25/2002 and 11/26/2002) on behalf of the United States in connection with the Duke Power NSR Case. *United States, et al. v. Duke Energy Corp.*, 1:00-CV-1262 (Middle District of North Carolina).
6. Expert reports and depositions (10/6/2004 and 10/7/2004; 7/10/2006) on behalf of the United States in connection with the American Electric Power NSR Cases. *United States, et al. v. American Electric Power Service Corp., et al.*, C2-99-1182, C2-99-1250 (Southern District of Ohio).
7. Affidavit (March 2005) on behalf of the Minnesota Center for Environmental Advocacy and others in the matter of the Application of Heron Lake BioEnergy LLC to construct and operate an ethanol production facility – submitted to the Minnesota Pollution Control Agency.
8. Expert Report and Deposition (10/31/2005 and 11/1/2005) on behalf of the United States in connection with the East Kentucky Power Cooperative NSR Case. *United States v. East Kentucky Power Cooperative, Inc.*, 5:04-cv-00034-KSF (Eastern District of Kentucky).
9. Affidavits and deposition on behalf of Basic Management Inc. (BMI) Companies in connection with the BMI vs. USA remediation cost recovery Case.
10. Expert Report on behalf of Penn Future and others in the Cambria Coke plant permit challenge in Pennsylvania.
11. Expert Report on behalf of the Appalachian Center for the Economy and the Environment and others in the Western Greenbrier permit challenge in West Virginia.
12. Expert Report, deposition (via telephone on January 26, 2007) on behalf of various Montana petitioners (Citizens Awareness Network (CAN), Women’s Voices for the Earth (WVE) and the Clark Fork Coalition (CFC)) in the Thompson River Cogeneration LLC Permit No. 3175-04 challenge.
13. Expert Report and deposition (2/2/07) on behalf of the Texas Clean Air Cities Coalition at the Texas State Office of Administrative Hearings (SOAH) in the matter of the permit challenges to TXU Project Apollo’s eight new proposed PRB-fired PC boilers located at seven TX sites.
14. Expert Testimony (July 2007) on behalf of the Izaak Walton League of America and others in connection with the acquisition of power by Xcel Energy from the proposed Gascoyne Power Plant – at the State of Minnesota, Office of Administrative Hearings for the Minnesota PUC (MPUC No. E002/CN-06-1518; OAH No. 12-2500-17857-2).



15. Affidavit (July 2007) Comments on the Big Cajun I Draft Permit on behalf of the Sierra Club – submitted to the Louisiana DEQ.
16. Expert Report and Deposition (12/13/2007) on behalf of Commonwealth of Pennsylvania – Dept. of Environmental Protection, State of Connecticut, State of New York, and State of New Jersey (Plaintiffs) in connection with the Allegheny Energy NSR Case. *Plaintiffs v. Allegheny Energy Inc., et al.*, 2:05cv0885 (Western District of Pennsylvania).
17. Expert Reports and Pre-filed Testimony before the Utah Air Quality Board on behalf of Sierra Club in the Sevier Power Plant permit challenge.
18. Expert Report and Deposition (October 2007) on behalf of MTD Products Inc., in connection with *General Power Products, LLC v MTD Products Inc.*, 1:06 CVA 0143 (Southern District of Ohio, Western Division) .
19. Expert Report and Deposition (June 2008) on behalf of Sierra Club and others in the matter of permit challenges (Title V: 28.0801-29 and PSD: 28.0803-PSD) for the Big Stone II unit, proposed to be located near Milbank, South Dakota.
20. Expert Reports, Affidavit, and Deposition (August 15, 2008) on behalf of Earthjustice in the matter of air permit challenge (CT-4631) for the Basin Electric Dry Fork station, under construction near Gillette, Wyoming before the Environmental Quality Council of the State of Wyoming.
21. Affidavits (May 2010/June 2010 in the Office of Administrative Hearings)/Declaration and Expert Report (November 2009 in the Office of Administrative Hearings) on behalf of NRDC and the Southern Environmental Law Center in the matter of the air permit challenge for Duke Cliffside Unit 6. Office of Administrative Hearing Matters 08 EHR 0771, 0835 and 0836 and 09 HER 3102, 3174, and 3176 (consolidated).
22. Declaration (August 2008), Expert Report (January 2009), and Declaration (May 2009) on behalf of Southern Alliance for Clean Energy in the matter of the air permit challenge for Duke Cliffside Unit 6. *Southern Alliance for Clean Energy et al., v. Duke Energy Carolinas, LLC*, Case No. 1:08-cv-00318-LHT-DLH (Western District of North Carolina, Asheville Division).
23. Declaration (August 2008) on behalf of the Sierra Club in the matter of Dominion Wise County plant MACT.us
24. Expert Report (June 2008) on behalf of Sierra Club for the Green Energy Resource Recovery Project, MACT Analysis.
25. Expert Report (February 2009) on behalf of Sierra Club and the Environmental Integrity Project in the matter of the air permit challenge for NRG Limestone’s proposed Unit 3 in Texas.
26. Expert Report (June 2009) on behalf of MTD Products, Inc., in the matter of *Alice Holmes and Vernon Holmes v. Home Depot USA, Inc., et al.*
27. Expert Report (August 2009) on behalf of Sierra Club and the Southern Environmental Law Center in the matter of the air permit challenge for Santee Cooper’s proposed Pee Dee plant in South Carolina).
28. Statements (May 2008 and September 2009) on behalf of the Minnesota Center for Environmental Advocacy to the Minnesota Pollution Control Agency in the matter of the Minnesota Haze State Implementation Plans.
29. Expert Report (August 2009) on behalf of Environmental Defense, in the matter of permit challenges to the proposed Las Brisas coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH).
30. Expert Report and Rebuttal Report (September 2009) on behalf of the Sierra Club, in the matter of challenges to the proposed Medicine Bow Fuel and Power IGL plant in Cheyenne, Wyoming.
31. Expert Report (December 2009) and Rebuttal reports (May 2010 and June 2010) on behalf of the United States in connection with the Alabama Power Company NSR Case. *United States v. Alabama Power Company*, CV-01-HS-152-S (Northern District of Alabama, Southern Division).
32. Pre-filed Testimony (October 2009) on behalf of Environmental Defense and others, in the matter of challenges to the proposed White Stallion Energy Center coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH).

33. Pre-filed Testimony (July 2010) and Written Rebuttal Testimony (August 2010) on behalf of the State of New Mexico Environment Department in the matter of Proposed Regulation 20.2.350 NMAC – *Greenhouse Gas Cap and Trade Provisions*, No. EIB 10-04 (R), to the State of New Mexico, Environmental Improvement Board.
34. Expert Report (August 2010) and Rebuttal Expert Report (October 2010) on behalf of the United States in connection with the Louisiana Generating NSR Case. *United States v. Louisiana Generating, LLC*, 09-CV100-RET-CN (Middle District of Louisiana) – Liability Phase.
35. Declaration (August 2010), Reply Declaration (November 2010), Expert Report (April 2011), Supplemental and Rebuttal Expert Report (July 2011) on behalf of the United States in the matter of DTE Energy Company and Detroit Edison Company (Monroe Unit 2). *United States of America v. DTE Energy Company and Detroit Edison Company*, Civil Action No. 2:10-cv-13101-BAF-RSW (Eastern District of Michigan).
36. Expert Report and Deposition (August 2010) as well as Affidavit (September 2010) on behalf of Kentucky Waterways Alliance, Sierra Club, and Valley Watch in the matter of challenges to the NPDES permit issued for the Trimble County power plant by the Kentucky Energy and Environment Cabinet to Louisville Gas and Electric, File No. DOW-41106-047.
37. Expert Report (August 2010), Rebuttal Expert Report (September 2010), Supplemental Expert Report (September 2011), and Declaration (November 2011) on behalf of Wild Earth Guardians in the matter of opacity exceedances and monitor downtime at the Public Service Company of Colorado (Xcel)’s Cherokee power plant. No. 09-cv-1862 (District of Colorado).
38. Written Direct Expert Testimony (August 2010) and Affidavit (February 2012) on behalf of Fall-Line Alliance for a Clean Environment and others in the matter of the PSD Air Permit for Plant Washington issued by Georgia DNR at the Office of State Administrative Hearing, State of Georgia (OSAH-BNR-AQ-1031707-98-WALKER).
39. Deposition (August 2010) on behalf of Environmental Defense, in the matter of the remanded permit challenge to the proposed Las Brisas coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH).
40. Expert Report, Supplemental/Rebuttal Expert Report, and Declarations (October 2010, November 2010, September 2012) on behalf of New Mexico Environment Department (Plaintiff-Intervenor), Grand Canyon Trust and Sierra Club (Plaintiffs) in the matter of *Plaintiffs v. Public Service Company of New Mexico* (PNM), Civil No. 1:02-CV-0552 BB/ATC (ACE) (District of New Mexico).
41. Expert Report (October 2010) and Rebuttal Expert Report (November 2010) (BART Determinations for PSCo Hayden and CSU Martin Drake units) to the Colorado Air Quality Commission on behalf of Coalition of Environmental Organizations.
42. Expert Report (November 2010) (BART Determinations for TriState Craig Units, CSU Nixon Unit, and PRPA Rawhide Unit) to the Colorado Air Quality Commission on behalf of Coalition of Environmental Organizations.
43. Declaration (November 2010) on behalf of the Sierra Club in connection with the Martin Lake Station Units 1, 2, and 3. *Sierra Club v. Energy Future Holdings Corporation and Luminant Generation Company LLC*, Case No. 5:10-cv-00156-DF-CMC (Eastern District of Texas, Texarkana Division).
44. Pre-Filed Testimony (January 2011) and Declaration (February 2011) to the Georgia Office of State Administrative Hearings (OSAH) in the matter of Minor Source HAPs status for the proposed Longleaf Energy Associates power plant (OSAH-BNR-AQ-1115157-60-HOWELLS) on behalf of the Friends of the Chattahoochee and the Sierra Club).
45. Declaration (February 2011) in the matter of the Draft Title V Permit for RRI Energy MidAtlantic Power Holdings LLC Shawville Generating Station (Pennsylvania), ID No. 17-00001 on behalf of the Sierra Club.
46. Expert Report (March 2011), Rebuttal Expert Report (June 2011) on behalf of the United States in *United States of America v. Cemex, Inc.*, Civil Action No. 09-cv-00019-MSK-MEH (District of Colorado).
47. Declaration (April 2011) and Expert Report (July 16, 2012) in the matter of the Lower Colorado River Authority (LCRA)’s Fayette (Sam Seymour) Power Plant on behalf of the Texas Campaign for the Environment. *Texas Campaign for the Environment v. Lower Colorado River Authority*, Civil Action No. 4:11-cv-00791 (Southern District of Texas, Houston Division).

48. Declaration (June 2011) on behalf of the Plaintiffs MYTAPN in the matter of Microsoft-Yes, Toxic Air Pollution-No (MYTAPN) v. State of Washington, Department of Ecology and Microsoft Corporation Columbia Data Center to the Pollution Control Hearings Board, State of Washington, Matter No. PCHB No. 10-162.
49. Expert Report (June 2011) on behalf of the New Hampshire Sierra Club at the State of New Hampshire Public Utilities Commission, Docket No. 10-261 – the 2010 Least Cost Integrated Resource Plan (LCIRP) submitted by the Public Service Company of New Hampshire (re. Merrimack Station Units 1 and 2).
50. Declaration (August 2011) in the matter of the Sandy Creek Energy Associates L.P. Sandy Creek Power Plant on behalf of Sierra Club and Public Citizen. *Sierra Club, Inc. and Public Citizen, Inc. v. Sandy Creek Energy Associates, L.P.*, Civil Action No. A-08-CA-648-LY (Western District of Texas, Austin Division).
51. Expert Report (October 2011) on behalf of the Defendants in the matter of *John Quiles and Jeanette Quiles et al. v. Bradford-White Corporation, MTD Products, Inc., Kohler Co., et al.*, Case No. 3:10-cv-747 (TJM/DEP) (Northern District of New York).
52. Declaration (October 2011) on behalf of the Plaintiffs in the matter of *American Nurses Association et al. (Plaintiffs), v. US EPA (Defendant)*, Case No. 1:08-cv-02198-RMC (US District Court for the District of Columbia).
53. Declaration (February 2012) and Second Declaration (February 2012) in the matter of *Washington Environmental Council and Sierra Club Washington State Chapter v. Washington State Department of Ecology and Western States Petroleum Association*, Case No. 11-417-MJP (Western District of Washington).
54. Expert Report (March 2012) and Supplemental Expert Report (November 2013) in the matter of *Environment Texas Citizen Lobby, Inc and Sierra Club v. ExxonMobil Corporation et al.*, Civil Action No. 4:10-cv-4969 (Southern District of Texas, Houston Division).
55. Declaration (March 2012) in the matter of *Center for Biological Diversity, et al. v. United States Environmental Protection Agency*, Case No. 11-1101 (consolidated with 11-1285, 11-1328 and 11-1336) (US Court of Appeals for the District of Columbia Circuit).
56. Declaration (March 2012) in the matter of *Sierra Club v. The Kansas Department of Health and Environment*, Case No. 11-105,493-AS (Holcomb power plant) (Supreme Court of the State of Kansas).
57. Declaration (March 2012) in the matter of the Las Brisas Energy Center *Environmental Defense Fund et al., v. Texas Commission on Environmental Quality*, Cause No. D-1-GN-11-001364 (District Court of Travis County, Texas, 261<sup>st</sup> Judicial District).
58. Expert Report (April 2012), Supplemental and Rebuttal Expert Report (July 2012), and Supplemental Rebuttal Expert Report (August 2012) on behalf of the states of New Jersey and Connecticut in the matter of the Portland Power plant *State of New Jersey and State of Connecticut (Intervenor-Plaintiff) v. RRI Energy Mid-Atlantic Power Holdings et al.*, Civil Action No. 07-CV-5298 (JKG) (Eastern District of Pennsylvania).
59. Declaration (April 2012) in the matter of the EPA’s EGU MATS Rule, on behalf of the Environmental Integrity Project.
60. Expert Report (August 2012) on behalf of the United States in connection with the Louisiana Generating NSR Case. *United States v. Louisiana Generating, LLC*, 09-CV100-RET-CN (Middle District of Louisiana) – Harm Phase.
61. Declaration (September 2012) in the Matter of the Application of *Energy Answers Incinerator, Inc.* for a Certificate of Public Convenience and Necessity to Construct a 120 MW Generating Facility in Baltimore City, Maryland, before the Public Service Commission of Maryland, Case No. 9199.
62. Expert Report (October 2012) on behalf of the Appellants (Robert Concilus and Leah Humes) in the matter of Robert Concilus and Leah Humes v. Commonwealth of Pennsylvania Department of Environmental Protection and Crawford Renewable Energy, before the Commonwealth of Pennsylvania Environmental Hearing Board, Docket No. 2011-167-R.
63. Expert Report (October 2012), Supplemental Expert Report (January 2013), and Affidavit (June 2013) in the matter of various Environmental Petitioners v. North Carolina DENR/DAQ and Carolinas Cement Company, before the Office of Administrative Hearings, State of North Carolina.

64. Pre-filed Testimony (October 2012) on behalf of No-Sag in the matter of the North Springfield Sustainable Energy Project before the State of Vermont, Public Service Board.
65. Pre-filed Testimony (November 2012) on behalf of Clean Wisconsin in the matter of Application of Wisconsin Public Service Corporation for Authority to Construct and Place in Operation a New Multi-Pollutant Control Technology System (ReACT) for Unit 3 of the Weston Generating Station, before the Public Service Commission of Wisconsin, Docket No. 6690-CE-197.
66. Expert Report (February 2013) on behalf of Petitioners in the matter of Credence Crematory, Cause No. 12-A-J-4538 before the Indiana Office of Environmental Adjudication.
67. Expert Report (April 2013), Rebuttal report (July 2013), and Declarations (October 2013, November 2013) on behalf of the Sierra Club in connection with the Luminant Big Brown Case. *Sierra Club v. Energy Future Holdings Corporation and Luminant Generation Company LLC*, Civil Action No. 6:12-cv-00108-WSS (Western District of Texas, Waco Division).
68. Declaration (April 2013) on behalf of Petitioners in the matter of *Sierra Club, et al., (Petitioners) v Environmental Protection Agency et al. (Respondents)*, Case No., 13-1112, (Court of Appeals, District of Columbia Circuit).
69. Expert Report (May 2013) and Rebuttal Expert Report (July 2013) on behalf of the Sierra Club in connection with the Luminant Martin Lake Case. *Sierra Club v. Energy Future Holdings Corporation and Luminant Generation Company LLC*, Civil Action No. 5:10-cv-0156-MHS-CMC (Eastern District of Texas, Texarkana Division).
70. Declaration (August 2013) on behalf of A. J. Acosta Company, Inc., in the matter of *A. J. Acosta Company, Inc., v. County of San Bernardino*, Case No. CIVSS803651.
71. Comments (October 2013) on behalf of the Washington Environmental Council and the Sierra Club in the matter of the Washington State Oil Refinery RACT (for Greenhouse Gases), submitted to the Washington State Department of Ecology, the Northwest Clean Air Agency, and the Puget Sound Clean Air Agency.
72. Statement (November 2013) on behalf of various Environmental Organizations in the matter of the Boswell Energy Center (BEC) Unit 4 Environmental Retrofit Project, to the Minnesota Public Utilities Commission, Docket No. E-015/M-12-920.
73. Expert Report (December 2013) on behalf of the United States in *United States of America v. Ameren Missouri*, Civil Action No. 4:11-cv-00077-RWS (Eastern District of Missouri, Eastern Division).
74. Expert Testimony (December 2013) on behalf of the Sierra Club in the matter of Public Service Company of New Hampshire Merrimack Station Scrubber Project and Cost Recovery, Docket No. DE 11-250, to the State of New Hampshire Public Utilities Commission.
75. Expert Report (January 2014) on behalf of Baja, Inc., in *Baja, Inc., v. Automotive Testing and Development Services, Inc. et. al*, Civil Action No. 8:13-CV-02057-GRA (District of South Carolina, Anderson/Greenwood Division).
76. Declaration (March 2014) on behalf of the Center for International Environmental Law, Chesapeake Climate Action Network, Friends of the Earth, Pacific Environment, and the Sierra Club (Plaintiffs) in the matter of *Plaintiffs v. the Export-Import Bank (Ex-Im Bank) of the United States*, Civil Action No. 13-1820 RC (District Court for the District of Columbia).
77. Declaration (April 2014) on behalf of Respondent-Intervenors in the matter of *Mexichem Specialty Resins Inc., et al., (Petitioners) v Environmental Protection Agency et al.*, Case No., 12-1260 (and Consolidated Case Nos. 12-1263, 12-1265, 12-1266, and 12-1267), (Court of Appeals, District of Columbia Circuit).
78. Direct Prefiled Testimony (June 2014) on behalf of the Michigan Environmental Council and the Sierra Club in the matter of the Application of DTE Electric Company for Authority to Implement a Power Supply Cost Recovery (PSCR) Plan in its Rate Schedules for 2014 Metered Jurisdictional Sales of Electricity, Case No. U-17319 (Michigan Public Service Commission).
79. Expert Report (June 2014) on behalf of ECM Biofilms in the matter of the US Federal Trade Commission (FTC) v. ECM Biofilms (FTC Docket #9358).

80. Direct Prefiled Testimony (August 2014) on behalf of the Michigan Environmental Council and the Sierra Club in the matter of the Application of Consumers Energy Company for Authority to Implement a Power Supply Cost Recovery (PSCR) Plan in its Rate Schedules for 2014 Metered Jurisdictional Sales of Electricity, Case No. U-17317 (Michigan Public Service Commission).
81. Declaration (July 2014) on behalf of Public Health Intervenors in the matter of *EME Homer City Generation v. US EPA* (Case No. 11-1302 and consolidated cases) relating to the lifting of the stay entered by the Court on December 30, 2011 (US Court of Appeals for the District of Columbia).
82. Expert Report (September 2014), Rebuttal Expert Report (December 2014) and Supplemental Expert Report (March 2015) on behalf of Plaintiffs in the matter of *Sierra Club and Montana Environmental Information Center (Plaintiffs) v. PPL Montana LLC, Avista Corporation, Puget Sound Energy, Portland General Electric Company, Northwestern Corporation, and Pacificorp (Defendants)*, Civil Action No. CV 13-32-BLG-DLC-JCL (US District Court for the District of Montana, Billings Division).
83. Expert Report (November 2014) on behalf of Niagara County, the Town of Lewiston, and the Villages of Lewiston and Youngstown in the matter of CWM Chemical Services, LLC New York State Department of Environmental Conservation (NYSDEC) Permit Application Nos.: 9-2934-00022/00225, 9-2934-00022/00231, 9-2934-00022/00232, and 9-2934-00022/00249 (pending).
84. *Declaration (January 2015) relating to Startup/Shutdown in the MATS Rule (EPA Docket ID No. EPA-HQ-OAR-2009-0234) on behalf of the Environmental Integrity Project.*
85. Pre-filed Direct Testimony (March 2015), Supplemental Testimony (May 2015), and Surrebuttal Testimony (December 2015) on behalf of Friends of the Columbia Gorge in the matter of the Application for a Site Certificate for the Troutdale Energy Center before the Oregon Energy Facility Siting Council.
86. Brief of Amici Curiae Experts in Air Pollution Control and Air Quality Regulation in Support of the Respondents, On Writs of Certiorari to the US Court of Appeals for the District of Columbia, No. 14-46, 47, 48. *Michigan et. al., (Petitioners) v. EPA et. al., Utility Air Regulatory Group (Petitioners) v. EPA et. al., National Mining Association et. al., (Petitioner) v. EPA et. al.*, (Supreme Court of the United States).
87. Expert Report (March 2015) and Rebuttal Expert Report (January 2016) on behalf of Plaintiffs in the matter of *Conservation Law Foundation v. Broadrock Gas Services LLC, Rhode Island LFG GENCO LLC, and Rhode Island Resource Recovery Corporation (Defendants)*, Civil Action No. 1:13-cv-00777-M-PAS (US District Court for the District of Rhode Island).
88. Declaration (April 2015) relating to various Technical Corrections for the MATS Rule (EPA Docket ID No. EPA-HQ-OAR-2009-0234) on behalf of the Environmental Integrity Project.
89. Direct Prefiled Testimony (May 2015) on behalf of the Michigan Environmental Council, the Natural Resources Defense Council, and the Sierra Club in the matter of the Application of DTE Electric Company for Authority to Increase its Rates, Amend its Rate Schedules and Rules Governing the Distribution and Supply of Electric Energy and for Miscellaneous Accounting Authority, Case No. U-17767 (Michigan Public Service Commission).
90. Expert Report (July 2015) and Rebuttal Expert Report (July 2015) on behalf of Plaintiffs in the matter of *Northwest Environmental Defense Center et. al., v. Cascade Kelly Holdings LLC, d/b/a Columbia Pacific Bio-Refinery, and Global Partners LP (Defendants)*, Civil Action No. 3:14-cv-01059-SI (US District Court for the District of Oregon, Portland Division).
91. Declaration (August 2015, Docket No. 1570376) in support of “Opposition of Respondent-Intervenors American Lung Association, et. al., to Tri-State Generation’s Emergency Motion;” Declaration (September 2015, Docket No. 1574820) in support of “Joint Motion of the State, Local Government, and Public Health Respondent-Intervenors for Remand Without Vacatur;” Declaration (October 2015) in support of “Joint Motion of the State, Local Government, and Public Health Respondent-Intervenors to State and Certain Industry Petitioners’ Motion to Govern, *White Stallion Energy Center, LLC v. US EPA*, Case No. 12-1100 (US Court of Appeals for the District of Columbia).
92. Declaration (September 2015) in support of the Draft Title V Permit for Dickerson Generating Station (Proposed Permit No 24-031-0019) on behalf of the Environmental Integrity Project.

93. Expert Report (Liability Phase) (December 2015) and Rebuttal Expert Report (February 2016) on behalf of Plaintiffs in the matter of *Natural Resources Defense Council, Inc., Sierra Club, Inc., Environmental Law and Policy Center, and Respiratory Health Association v. Illinois Power Resources LLC, and Illinois Power Resources Generating LLC (Defendants)*, Civil Action No. 1:13-cv-01181 (US District Court for the Central District of Illinois, Peoria Division).
94. Declaration (December 2015) in support of the Petition to Object to the Title V Permit for Morgantown Generating Station (Proposed Permit No 24-017-0014) on behalf of the Environmental Integrity Project.
95. Expert Report (November 2015) on behalf of Appellants in the matter of *Sierra Club, et al. v. Craig W. Butler, Director of Ohio Environmental Protection Agency et al.*, ERAC Case No. 14-256814.
96. Affidavit (January 2016) on behalf of Bridgewatch Detroit in the matter of *Bridgewatch Detroit v. Waterfront Petroleum Terminal Co., and Waterfront Terminal Holdings, LLC.*, in the Circuit Court for the County of Wayne, State of Michigan.
97. Expert Report (February 2016) and Rebuttal Expert Report (July 2016) on behalf of the challengers in the matter of the Delaware Riverkeeper Network, Clean Air Council, et. al., vs. Commonwealth of Pennsylvania Department of Environmental Protection and R. E. Gas Development LLC regarding the Geyer well site before the Pennsylvania Environmental Hearing Board.
98. Direct Testimony (May 2016) in the matter of Tesoro Savage LLC Vancouver Energy Distribution Terminal, Case No. 15-001 before the State of Washington Energy Facility Site Evaluation Council.
99. Declaration (June 2016) relating to deficiencies in air quality analysis for the proposed Millenium Bulk Terminal, Port of Longview, Washington.
100. Declaration (December 2016) relating to EPA's refusal to set limits on PM emissions from coal-fired power plants that reflect pollution reductions achievable with fabric filters on behalf of Environmental Integrity Project, Clean Air Council, Chesapeake Climate Action Network, Downwinders at Risk represented by Earthjustice in the matter of *ARIPPA v EPA, Case No. 15-1180*. (D.C. Circuit Court of Appeals).
101. Expert Report (January 2017) on the Environmental Impacts Analysis associated with the Huntley and Huntley Poseidon Well Pad on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.
102. Expert Report (January 2017) on the Environmental Impacts Analysis associated with the Apex Energy Backus Well Pad on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.
103. Expert Report (January 2017) on the Environmental Impacts Analysis associated with the Apex Energy Drakulic Well Pad on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.
104. Expert Report (January 2017) on the Environmental Impacts Analysis associated with the Apex Energy Deutsch Well Pad on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.
105. Affidavit (February 2017) pertaining to deficiencies water discharge compliance issues at the Wood River Refinery in the matter of *People of the State of Illinois (Plaintiff) v. Phillips 66 Company, ConocoPhillips Company, WRB Refining LP (Defendants)*, Case No. 16-CH-656, (Circuit Court for the Third Judicial Circuit, Madison County, Illinois).
106. Expert Report (March 2017) on behalf of the Plaintiff pertaining to non-degradation analysis for waste water discharges from a power plant in the matter of *Sierra Club (Plaintiff) v. Pennsylvania Department of Environmental Protection (PADEP) and Lackawanna Energy Center*, Docket No. 2016-047-L (consolidated), (Pennsylvania Environmental Hearing Board).
107. Expert Report (March 2017) on behalf of the Plaintiff pertaining to air emissions from the Heritage incinerator in East Liverpool, Ohio in the matter of *Save our County (Plaintiff) v. Heritage Thermal Services, Inc. (Defendant)*, Case No. 4:16-CV-1544-BYP, (US District Court for the Northern District of Ohio, Eastern Division).

108. Rebuttal Expert Report (June 2017) on behalf of Plaintiffs in the matter of *Casey Voight and Julie Voight (Plaintiffs) v Coyote Creek Mining Company LLC (Defendant)*, Civil Action No. 1:15-CV-00109 (US District Court for the District of North Dakota, Western Division).
109. Expert Affidavit (August 2017) and Penalty/Remedy Expert Affidavit (October 2017) on behalf of Plaintiff in the matter of *Wildearth Guardians (Plaintiff) v Colorado Springs Utility Board (Defendant)*, Civil Action No. 1:15-cv-00357-CMA-CBS (US District Court for the District of Colorado).
110. Expert Report (August 2017) on behalf of Appellant in the matter of *Patricia Ann Troiano (Appellant) v. Upper Burrell Township Zoning Hearing Board (Appellee)*, Court of Common Pleas of Westmoreland County, Pennsylvania, Civil Division.
111. Expert Report (October 2017), Supplemental Expert Report (October 2017), and Rebuttal Expert Report (November 2017) on behalf of Defendant in the matter of *Oakland Bulk and Oversized Terminal (Plaintiff) v City of Oakland (Defendant)*, Civil Action No. 3:16-cv-07014-VC (US District Court for the Northern District of California, San Francisco Division).
112. Declaration (December 2017) on behalf of the Environmental Integrity Project in the matter of permit issuance for ATI Flat Rolled Products Holdings, Breckenridge, PA to the Allegheny County Health Department.
113. Expert Report (Harm Phase) (January 2018) and Rebuttal Expert Report (Harm Phase) (May 2018) on behalf of Plaintiffs in the matter of *Natural Resources Defense Council, Inc., Sierra Club, Inc., and Respiratory Health Association v. Illinois Power Resources LLC, and Illinois Power Resources Generating LLC (Defendants)*, Civil Action No. 1:13-cv-01181 (US District Court for the Central District of Illinois, Peoria Division).
114. Declaration (February 2018) on behalf of the Chesapeake Bay Foundation, et. al., in the matter of the Section 126 Petition filed by the state of Maryland in *State of Maryland v. Pruitt (Defendant)*, Civil Action No. JKB-17-2939 (Consolidated with No. JKB-17-2873) (US District Court for the District of Maryland).
115. Direct Pre-filed Testimony (March 2018) on behalf of the National Parks Conservation Association (NPCA) in the matter of *NPCA v State of Washington, Department of Ecology and BP West Coast Products, LLC*, PCHB No. 17-055 (Pollution Control Hearings Board for the State of Washington).
116. Expert Affidavit (April 2018) and Second Expert Affidavit (May 2018) on behalf of Petitioners in the matter of *Coosa River Basin Initiative and Sierra Club (Petitioners) v State of Georgia Environmental Protection Division, Georgia Department of Natural Resources (Respondent) and Georgia Power Company (Intervenor/Respondent)*, Docket Nos: 1825406-BNR-WW-57-Howells and 1826761-BNR-WW-57-Howells, Office of State Administrative Hearings, State of Georgia.

C. Occasions where Dr. Sahu has provided oral testimony in depositions, at trial or in similar proceedings include the following:

117. Deposition on behalf of Rocky Mountain Steel Mills, Inc. located in Pueblo, Colorado – dealing with the manufacture of steel in mini-mills including methods of air pollution control and BACT in steel mini-mills and opacity issues at this steel mini-mill.
118. Trial Testimony (February 2002) on behalf of Rocky Mountain Steel Mills, Inc. in Denver District Court.
119. Trial Testimony (February 2003) on behalf of the United States in the Ohio Edison NSR Cases, *United States, et al. v. Ohio Edison Co., et al.*, C2-99-1181 (Southern District of Ohio).
120. Trial Testimony (June 2003) on behalf of the United States in the Illinois Power NSR Case, *United States v. Illinois Power Co., et al.*, 99-833-MJR (Southern District of Illinois).
121. Deposition (10/20/2005) on behalf of the United States in connection with the Cinergy NSR Case. *United States, et al. v. Cinergy Corp., et al.*, IP 99-1693-C-M/S (Southern District of Indiana).
122. Oral Testimony (August 2006) on behalf of the Appalachian Center for the Economy and the Environment re. the Western Greenbrier plant, WV before the West Virginia DEP.

123. Oral Testimony (May 2007) on behalf of various Montana petitioners (Citizens Awareness Network (CAN), Women's Voices for the Earth (WVE) and the Clark Fork Coalition (CFC)) re. the Thompson River Cogeneration plant before the Montana Board of Environmental Review.
124. Oral Testimony (October 2007) on behalf of the Sierra Club re. the Sevier Power Plant before the Utah Air Quality Board.
125. Oral Testimony (August 2008) on behalf of the Sierra Club and Clean Water re. Big Stone Unit II before the South Dakota Board of Minerals and the Environment.
126. Oral Testimony (February 2009) on behalf of the Sierra Club and the Southern Environmental Law Center re. Santee Cooper Pee Dee units before the South Carolina Board of Health and Environmental Control.
127. Oral Testimony (February 2009) on behalf of the Sierra Club and the Environmental Integrity Project re. NRG Limestone Unit 3 before the Texas State Office of Administrative Hearings (SOAH) Administrative Law Judges.
128. Deposition (July 2009) on behalf of MTD Products, Inc., in the matter of *Alice Holmes and Vernon Holmes v. Home Depot USA, Inc., et al.*
129. Deposition (October 2009) on behalf of Environmental Defense and others, in the matter of challenges to the proposed Coletto Creek coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH).
130. Deposition (October 2009) on behalf of Environmental Defense, in the matter of permit challenges to the proposed Las Brisas coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH).
131. Deposition (October 2009) on behalf of the Sierra Club, in the matter of challenges to the proposed Medicine Bow Fuel and Power IGL plant in Cheyenne, Wyoming.
132. Deposition (October 2009) on behalf of Environmental Defense and others, in the matter of challenges to the proposed Tenaska coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH). (April 2010).
133. Oral Testimony (November 2009) on behalf of the Environmental Defense Fund re. the Las Brisas Energy Center before the Texas State Office of Administrative Hearings (SOAH) Administrative Law Judges.
134. Deposition (December 2009) on behalf of Environmental Defense and others, in the matter of challenges to the proposed White Stallion Energy Center coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH).
135. Oral Testimony (February 2010) on behalf of the Environmental Defense Fund re. the White Stallion Energy Center before the Texas State Office of Administrative Hearings (SOAH) Administrative Law Judges.
136. Deposition (June 2010) on behalf of the United States in connection with the Alabama Power Company NSR Case. *United States v. Alabama Power Company*, CV-01-HS-152-S (Northern District of Alabama, Southern Division).
137. Trial Testimony (September 2010) on behalf of Commonwealth of Pennsylvania – Dept. of Environmental Protection, State of Connecticut, State of New York, State of Maryland, and State of New Jersey (Plaintiffs) in connection with the Allegheny Energy NSR Case in US District Court in the Western District of Pennsylvania. *Plaintiffs v. Allegheny Energy Inc., et al.*, 2:05cv0885 (Western District of Pennsylvania).
138. Oral Direct and Rebuttal Testimony (September 2010) on behalf of Fall-Line Alliance for a Clean Environment and others in the matter of the PSD Air Permit for Plant Washington issued by Georgia DNR at the Office of State Administrative Hearing, State of Georgia (OSAH-BNR-AQ-1031707-98-WALKER).
139. Oral Testimony (September 2010) on behalf of the State of New Mexico Environment Department in the matter of Proposed Regulation 20.2.350 NMAC – *Greenhouse Gas Cap and Trade Provisions*, No. EIB 10-04 (R), to the State of New Mexico, Environmental Improvement Board.
140. Oral Testimony (October 2010) on behalf of the Environmental Defense Fund re. the Las Brisas Energy Center before the Texas State Office of Administrative Hearings (SOAH) Administrative Law Judges.



141. Oral Testimony (November 2010) regarding BART for PSCo Hayden, CSU Martin Drake units before the Colorado Air Quality Commission on behalf of the Coalition of Environmental Organizations.
142. Oral Testimony (December 2010) regarding BART for TriState Craig Units, CSU Nixon Unit, and PRPA Rawhide Unit) before the Colorado Air Quality Commission on behalf of the Coalition of Environmental Organizations.
143. Deposition (December 2010) on behalf of the United States in connection with the Louisiana Generating NSR Case. *United States v. Louisiana Generating, LLC*, 09-CV100-RET-CN (Middle District of Louisiana).
144. Deposition (February 2011 and January 2012) on behalf of Wild Earth Guardians in the matter of opacity exceedances and monitor downtime at the Public Service Company of Colorado (Xcel)'s Cherokee power plant. No. 09-cv-1862 (D. Colo.).
145. Oral Testimony (February 2011) to the Georgia Office of State Administrative Hearings (OSAH) in the matter of Minor Source HAPs status for the proposed Longleaf Energy Associates power plant (OSAH-BNR-AQ-1115157-60-HOWELLS) on behalf of the Friends of the Chattahoochee and the Sierra Club).
146. Deposition (August 2011) on behalf of the United States in *United States of America v. Cemex, Inc.*, Civil Action No. 09-cv-00019-MSK-MEH (District of Colorado).
147. Deposition (July 2011) and Oral Testimony at Hearing (February 2012) on behalf of the Plaintiffs MYTAPN in the matter of Microsoft-Yes, Toxic Air Pollution-No (MYTAPN) v. State of Washington, Department of Ecology and Microsoft Corporation Columbia Data Center to the Pollution Control Hearings Board, State of Washington, Matter No. PCHB No. 10-162.
148. Oral Testimony at Hearing (March 2012) on behalf of the United States in connection with the Louisiana Generating NSR Case. *United States v. Louisiana Generating, LLC*, 09-CV100-RET-CN (Middle District of Louisiana).
149. Oral Testimony at Hearing (April 2012) on behalf of the New Hampshire Sierra Club at the State of New Hampshire Public Utilities Commission, Docket No. 10-261 – the 2010 Least Cost Integrated Resource Plan (LCIRP) submitted by the Public Service Company of New Hampshire (re. Merrimack Station Units 1 and 2).
150. Oral Testimony at Hearing (November 2012) on behalf of Clean Wisconsin in the matter of Application of Wisconsin Public Service Corporation for Authority to Construct and Place in Operation a New Multi-Pollutant Control Technology System (ReACT) for Unit 3 of the Weston Generating Station, before the Public Service Commission of Wisconsin, Docket No. 6690-CE-197.
151. Deposition (March 2013) in the matter of various Environmental Petitioners v. North Carolina DENR/DAQ and Carolinas Cement Company, before the Office of Administrative Hearings, State of North Carolina.
152. Deposition (August 2013) on behalf of the Sierra Club in connection with the Luminant Big Brown Case. *Sierra Club v. Energy Future Holdings Corporation and Luminant Generation Company LLC*, Civil Action No. 6:12-cv-00108-WSS (Western District of Texas, Waco Division).
153. Deposition (August 2013) on behalf of the Sierra Club in connection with the Luminant Martin Lake Case. *Sierra Club v. Energy Future Holdings Corporation and Luminant Generation Company LLC*, Civil Action No. 5:10-cv-0156-MHS-CMC (Eastern District of Texas, Texarkana Division).
154. Deposition (February 2014) on behalf of the United States in *United States of America v. Ameren Missouri*, Civil Action No. 4:11-cv-00077-RWS (Eastern District of Missouri, Eastern Division).
155. Trial Testimony (February 2014) in the matter of *Environment Texas Citizen Lobby, Inc and Sierra Club v. ExxonMobil Corporation et al.*, Civil Action No. 4:10-cv-4969 (Southern District of Texas, Houston Division).
156. Trial Testimony (February 2014) on behalf of the Sierra Club in connection with the Luminant Big Brown Case. *Sierra Club v. Energy Future Holdings Corporation and Luminant Generation Company LLC*, Civil Action No. 6:12-cv-00108-WSS (Western District of Texas, Waco Division).
157. Deposition (June 2014) and Trial (August 2014) on behalf of ECM Biofilms in the matter of the *US Federal Trade Commission (FTC) v. ECM Biofilms* (FTC Docket #9358).

158. Deposition (February 2015) on behalf of Plaintiffs in the matter of *Sierra Club and Montana Environmental Information Center (Plaintiffs) v. PPL Montana LLC, Avista Corporation, Puget Sound Energy, Portland General Electric Company, Northwestern Corporation, and PacifiCorp (Defendants)*, Civil Action No. CV 13-32-BLG-DLC-JCL (US District Court for the District of Montana, Billings Division).
159. Oral Testimony at Hearing (April 2015) on behalf of Niagara County, the Town of Lewiston, and the Villages of Lewiston and Youngstown in the matter of CWM Chemical Services, LLC New York State Department of Environmental Conservation (NYSDEC) Permit Application Nos.: 9-2934-00022/00225, 9-2934-00022/00231, 9-2934-00022/00232, and 9-2934-00022/00249 (pending).
160. Deposition (August 2015) on behalf of Plaintiff in the matter of *Conservation Law Foundation (Plaintiff) v. Broadrock Gas Services LLC, Rhode Island LFG GENCO LLC, and Rhode Island Resource Recovery Corporation (Defendants)*, Civil Action No. 1:13-cv-00777-M-PAS (US District Court for the District of Rhode Island).
161. Testimony at Hearing (August 2015) on behalf of the Sierra Club in the matter of *Amendments to 35 Illinois Administrative Code Parts 214, 217, and 225* before the Illinois Pollution Control Board, R15-21.
162. Deposition (May 2015) on behalf of Plaintiffs in the matter of *Northwest Environmental Defense Center et. al., (Plaintiffs) v. Cascade Kelly Holdings LLC, d/b/a Columbia Pacific Bio-Refinery, and Global Partners LP (Defendants)*, Civil Action No. 3:14-cv-01059-SI (US District Court for the District of Oregon, Portland Division).
163. Trial Testimony (October 2015) on behalf of Plaintiffs in the matter of *Northwest Environmental Defense Center et. al., (Plaintiffs) v. Cascade Kelly Holdings LLC, d/b/a Columbia Pacific Bio-Refinery, and Global Partners LP (Defendants)*, Civil Action No. 3:14-cv-01059-SI (US District Court for the District of Oregon, Portland Division).
164. Deposition (April 2016) on behalf of the Plaintiffs in *UNatural Resources Defense Council, Respiratory Health Association, and Sierra Club (Plaintiffs) v. Illinois Power Resources LLC and Illinois Power Resources Generation LLC (Defendants)*, Civil Action No. 1:13-cv-01181 (Central District of Illinois, Peoria Division).
165. Trial Testimony at Hearing (July 2016) in the matter of Tesoro Savage LLC Vancouver Energy Distribution Terminal, Case No. 15-001 before the State of Washington Energy Facility Site Evaluation Council.
166. Trial Testimony (December 2016) on behalf of the challengers in the matter of the Delaware Riverkeeper Network, Clean Air Council, et. al., vs. Commonwealth of Pennsylvania Department of Environmental Protection and R. E. Gas Development LLC regarding the Geyer well site before the Pennsylvania Environmental Hearing Board.
167. Trial Testimony (July-August 2016) on behalf of the United States in *United States of America v. Ameren Missouri*, Civil Action No. 4:11-cv-00077-RWS (Eastern District of Missouri, Eastern Division).
168. Trial Testimony (January 2017) on the Environmental Impacts Analysis associated with the Huntley and Huntley Poseidon Well Pad Hearing on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.
169. Trial Testimony (January 2017) on the Environmental Impacts Analysis associated with the Apex energy Backus Well Pad Hearing on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.
170. Trial Testimony (January 2017) on the Environmental Impacts Analysis associated with the Apex energy Drakulic Well Pad Hearing on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.
171. Trial Testimony (January 2017) on the Environmental Impacts Analysis associated with the Apex energy Deutsch Well Pad Hearing on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.
172. Deposition Testimony (July 2017) on behalf of Plaintiffs in the matter of *Casey Voight and Julie Voight v Coyote Creek Mining Company LLC (Defendant)* Civil Action No. 1:15-CV-00109 (US District Court for the District of North Dakota, Western Division).

173. Deposition Testimony (November 2017) on behalf of Defendant in the matter of *Oakland Bulk and Oversized Terminal (Plaintiff) v City of Oakland (Defendant)*, Civil Action No. 3:16-cv-07014-VC (US District Court for the Northern District of California, San Francisco Division).
174. Deposition Testimony (December 2017) on behalf of Plaintiff in the matter of *Wildearth Guardians (Plaintiff) v Colorado Springs Utility Board (Defendant)* Civil Action No. 1:15-cv-00357-CMA-CBS (US District Court for the District of Colorado).
175. Deposition Testimony (January 2018) in the matter of National Parks Conservation Association (NPCA) v. State of Washington Department of Ecology and British Petroleum (BP) before the Washington Pollution Control Hearing Board, Case No. 17-055.
176. Trial Testimony (January 2018) on behalf of Defendant in the matter of *Oakland Bulk and Oversized Terminal (Plaintiff) v City of Oakland (Defendant)*, Civil Action No. 3:16-cv-07014-VC (US District Court for the Northern District of California, San Francisco Division).
177. Trial Testimony (April 2018) on behalf of the National Parks Conservation Association (NPCA) in the matter of NPCA v State of Washington, Department of Ecology and BP West Coast Products, LLC, PCHB No. 17-055 (Pollution Control Hearings Board for the State of Washington).

## **ATTACHMENT B – Technical Paper**