EXPERT REPORT

On

NOx Emissions from the Wheelabrator Baltimore Municipal Waste Incinerator in Baltimore City, owned and operated by Wheelabrator Baltimore, L.P. ("Wheelabrator")

by

Dr. Ranajit (Ron) Sahu, Consultant

May 10, 2018

Introduction

In November of 2017, the Maryland Department of the Environment (MDE) shared with public stakeholders a draft regulation, dated November 17, 2017, that would revise Maryland’s standards limiting emissions of nitrogen oxides (NOx) from large municipal waste combustors. The proposed revisions are to Title 26 Department of the Environment, Subtitle 11 Air Quality, Chapter 08 Control of Incinerators of COMAR. There are two large municipal waste combustors in Maryland, the larger being the Wheelabrator facility in Baltimore City.

I was asked to review certain materials relating to the Wheelabrator Baltimore municipal waste combustor and to give my opinion on what is achievable in terms of NOx reduction at this facility. Specifically, I reviewed the following materials in the preparation of this report: (1) the 2017 Fuel Tech Report on optimization of the existing controls at the facility; (2) the 2016 Quinapoxet Report; on optimization of the existing controls at the facility; (3) 1-hour averaged NOx CEMS data collected at the three boilers at the Wheelabrator facility for the calendar year 2017; ² and (4) the November 2017 draft regulation circulated by MDE. As discussed in more detail below, I have previously commented on an optimization study performed in 2016 (the Quinapoxet Study).

My observations and conclusions based on this review are set forth below.

¹ Resume provided in Attachment A.

² In early 2018, MDE began making hourly CEMS data from the Wheelabrator facility available to the public online. The data that I reviewed is available under Special Studies, Wheelabrator Annual CEM Data Reports, Data, at the following link: http://mde.maryland.gov/programs/Air/Pages/ARAResearch.aspx.
NOx Reasonably Achievable Control Technology (RACT) for the Wheelabrator Baltimore Facility

Wheelabrator operates a municipal waste combustion facility in Baltimore. As noted in its application for its Title V permit application, submitted in 2006:

“The facility is a municipal solid waste resource recovery facility (SIC Code 4953). It consists of three municipal waste combustors that generate steam….”

Each of these three combustors (hereafter “boilers” or “Units”) and noted as Boiler 1 (Unit 1), Boiler 2 (Unit 2), and Boiler 3 (Unit 3), respectively – are identical as described by Wheelabrator in its 2006 application:

“…750 ton per day Wheelabrator-Frye mass burn waterwall municipal waste combustor equipped with SNCR, SDA, ESP and activated carbon injection systems. Combustion gases are exhausted through a stack…that contains three flues (one for each of the three combustors)…”

In its November 2017 proposed regulation for the Wheelabrator facility, MDE effectively proposed a NOx RACT level with specified numerical limits (as noted below) followed by a potential future lower NOx limit— the latter to be developed based on the results of a feasibility study to be submitted by Wheelabrator to MDE in 2020. The November 2017 proposed regulation requires that the analysis will be prepared by an independent third party.

The proposed NOx RACT for Wheelabrator set forth in the November 2017 rule is:

A. a 24-hour block average emission rate\(^3\) of 150 parts per million (ppmv); and

B. a 145 ppmv rate over a 30-day period – both corrected to 7% oxygen.\(^4\)

Per the proposed RACT, the 150 ppmv level is to be achieved by 2019 and the 145 ppmv level is to be achieved by 2020. The November 17, 2017 draft regulation also includes section E, “Additional NOx Emission Control Requirements,” which states that “(1) Not

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\(^3\) The use of the term, “emission rate” to describe the proposed RACT level, is, in my opinion, inaccurate. Typically emission rate denotes the mass emissions of a pollutant (i.e., in pounds, grams, tons, etc.) either per unit time (i.e., gram/second, pound/hour, ton/year, etc.) or per unit of process input (i.e., lb/million Btu of heat input, lb/ton of waste burned), or per unit of process output (i.e., lb/pound of steam generated), etc. The proposed NO\(_x\) RACT levels – i.e., parts per million in the exhaust gases, corrected to 7\% oxygen, are, more properly, concentrations, not emission rates.

\(^4\) In all instances in this Declarations, it should be assumed that NO\(_x\) levels discussed are always corrected to the 7\% oxygen basis, whether explicitly stated or otherwise.
later than January 1, 2020, the owner or operator of Wheelabrator Baltimore, Inc. shall submit a feasibility analysis for additional control of NOx emissions from the Wheelabrator Baltimore Inc. facility to the Department.”

**Optimizing SNCR at the Wheelabrator, Baltimore Facility**

Briefly, in SNCR, a NOx-reducing reagent, such as ammonia or urea is injected into the exhaust gases from a boiler, within a specified gas temperature range (typically when the gas temperature is between 1800-2100 F). At Wheelabrator, urea is injected as liquid droplets using a number of injectors, all located in a single plane at each boiler. Urea converts to ammonia and some ammonia leaves the system. The ammonia that leaves the system is considered unreacted ammonia and is known as the “ammonia slip.” The goal of SNCR is to reduce NOx while keeping ammonia slip to a low level. Details of the existing SNCR system at Wheelabrator are provided in the 2017 Fuel Tech Report which is discussed and quoted from extensively later in this document.

I am aware of at least two attempts at “optimizing” the performance of the existing SNCR systems at Wheelabrator since 2016. From February to March of 2016, Wheelabrator conducted an optimization study5 (“Quinapoxet Study”). I have previously commented on the significant technical shortcomings of this study.6 Nonetheless, and in spite of these shortcomings, this study showed that certain, modest NOx reductions were possible with additional urea flow and modification of SNCR configuration. More recently, Fuel Tech completed a 4-day optimization study in early June 2017,7 which was followed by additional optimization testing of all 3 boilers from June 12-14, 2017 and June 20-29, 2017.8 I discuss the findings of this work in the next section.

**Findings in the 2017 Fuel Tech Report**

I note first that Fuel Tech was charged with optimizing the current SNCR controls at each boiler to achieve NOx levels below 150 ppm.

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5 Final Report NOx Control System Optimization at the Wheelabrator Baltimore WTE Facility, Quinapoxet Solutions, (undated, 2016), Quinapoxet Solutions.


7 Bisnett, Michael, Fuel Tech, NOx Optimization Project Wheelabrator Baltimore Inc., Baltimore, Maryland Units 1,2 & 3, June 5-9, 2017 (“2017 Fuel Tech Report”). I received an incomplete pdf copy of the report with 24 pdf pages. The last page of the report (before two non-numbered pages containing emails) is noted as “Page 22 of 31.”

8 The data for the June 12-14 and 20-29 days was submitted to MDE separately from the Fuel Tech Report.
“Fuel Tech Inc. (FTI) was contracted by Wheelabrator to conduct SNCR system optimization testing at their Waste to Energy (WTE) facility located in Baltimore, Maryland. The objective was to obtain provide further optimization of the SNCR system to reduce NOx levels below 150 ppmdc (corrected to 7%02) while minimizing ammonia slip…”

Briefly, Fuel Tech described the optimization details as follows:

“For this optimization program, additional changes were made to the existing SNCR equipment to allow for more flexibility for enhancing NOx removal. These changes primarily included installation of new NOx injector tips with 30 deg up angle cone spray and use of alternate rear furnace wall injector ports. The use of the additional rear wall injector ports and modified injector tips enhanced the coverage of the injectors allowed for more flexibility to optimize the SNCR system to control NOx below the 150 ppmdc (corrected to 7% 02) target while simultaneously maintaining low ammonia slip levels.”

Admittedly, the Fuel Tech optimization work was of short duration, mainly indicating (and proving, as I show later) that lower than 150 ppm NOx levels can be achieved, even on a short-term, i.e., hourly basis at each boiler. Thus, it was a proof-of-concept study.

As far as baseline NOx levels during the 2017 Fuel Tech study, Fuel Tech notes the following:

“Baseline NOx values on all 3 units were close to previous optimization testing levels of around 200+ ppmdc. Overall the during this testing period the baseline varied in the range of 190 to 220 ppmdc It appeared that earlier in the day the baseline was lower and increased during the day. The plant confirmed that the NOx would increase at times and but the mechanism or its consistency was not understood.”

The allusion to “previous optimization testing” is not entirely clear. It could be referencing the 2016 Quinapoxet Study, which did observe baseline levels around 200 ppm. I note that after years of experience with its boilers, it is troubling that Wheelabrator still does not have a reasonable understanding of the NOx levels from its boilers, as evidenced by Fuel Tech’s comment in the last sentence above.

Fuel Tech reports the results of its optimization work at Unit 3 (the first unit at which the work was done on June 6, 2017), as follows:

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9 2017 Fuel Tech Report, p. 3.

10 2017 Fuel Tech Report, p. 3.

“The results were very good. Using the same urea dosage of 15 gph, with an NSR of 1.14, the NOx reduction increased from 37.5 to 42.7%, utilization increased from 32.9% to 37.4% and the NOx dropped to 130 ppm. Individual injector water flow was 1.33 gpm at an air pressure of 40 psig. The measured ammonia slip increased slightly to 3.3 ppm from 1.1 ppm and stack observation indicated there was no visible plume. Making the change to the angled up tips showed that releasing the urea higher in the furnace with the right injector configuration was very beneficial….The initial Unit 3 optimization results were very positive and predictable and, as such, were used as the starting point for further optimization of the other 2 units.”

Shown below are the hourly NOx data for Unit 3 from the CEMS for June 6, 2017. It confirms that levels as low as 135 ppm on an hourly basis, were obtained at Unit 3 during the optimization.

At Unit 1, the next Unit subjected to optimization, on June 7, 2017, Fuel Tech describes the results as follows:

“A baseline NOx value was obtained prior to the first test. For the 1st test NOx was kept close to 140 ppm with 15 gph of urea and a measured slip of 1.7 ppm (internal citation omitted) and utilization rate of 36.5%. This proved that the final configuration from Unit 3 carried over successfully to Unit 1 as SNCR performance was very good. (internal

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13 I do note that, while the Fuel Tech Report shows a NOx level as low as 130 ppm, the CEMS data for that day do not show that level. This discrepancy may simply be due to the different instruments used to measure the NOx levels (i.e., Fuel Tech’s instrument and the CEM).
citation omitted). Given the successful duplication of results on Unit 1, further optimization was done to this configuration to evaluate the impact on SNCR performance.

Increasing the urea dosage (internal citation omitted) from 15 to 20 gph was done to determine if there is a point where increasing the urea dosage will not lead to a reasonable increase in the NOx reduction with the 6 injector configuration and essentially determining a point of diminishing returns. Increasing to 20 gph of urea reduced NOx to 130 ppmfdc but the utilization dropped from 34.7 to 32.9% while ammonia slip increased slightly from 1.7 to 2.7 ppm evidence that urea rates above 20 gph, ammonia slip would increase very quickly.”

Shown below are the hourly NOx levels measured by the CEM on Unit 1. It confirms that levels as low as 125 ppm were obtained during the optimization.

Finally, for Unit 2, the last unit optimized by Fuel Tech on June 8, 2017, Fuel Tech describes the result as follows:

“Starting up the SNCR system for the first set of tests went without incident and the NOx was reduced to 140 ppmfdc. (Figure 17) This was achieved with 4 injectors at 1 gpm water flow, 15 gph urea flow, and 40 psig air pressure. NOx levels were about 140 ppmfdc and ammonia slip...”


15 As in the case of Unit 3, there appears to be a slight discrepancy between the NOx levels discussed in the Fuel Tech Report and the NOx CEM. For Unit 2, the CEM showed a value of 125 ppm, while the Fuel Tech Report notes 130 ppm.
was 2.9 ppm….Increasing the urea from 15 to 20 gph reduced NOx to about 135 ppm\textsubscript{dc} but the slip increases to 3.9 ppm.”\textsuperscript{16}

Similar to the data presented above for the other two units, I show below the NOx CEM data for Unit 2 for June 8, 2017. This data shows levels lower than 140 ppm with a low of 138 ppm.

Summarizing its results and relating it to the objective of the study, Fuel Tech stated:

“The results of FTI's short term SNCR optimization testing indicated that use of 30 deg up angled injector tips and injector total liquid flow of 1 gpm provided additional capability for SNCR systems to achieve and maintain NOx emission level of 150 ppm\textsubscript{dc} with minimal ammonia slip.”\textsuperscript{17}

Thus, it is clear that, a level of 150 ppm NO\textsubscript{x} can be achieved today, at each unit at Wheelabrator. In fact, as shown above, hourly levels in the 125-140 range were achievable at each unit during mid-2017.

The proposed RACT limits for Wheelabrator include averaging times longer than hourly – i.e, 150 ppm using a block average of 24 hours and 145 ppm using a 30 day average. The longer the averaging time, the more the ability to smooth out variations. Given these proposed averaging times, and reviewing the results of the 2017 Fuel Tech optimization work, it is my opinion that the proposed RACT levels can be lowered – likely from 150

\textsuperscript{16} 2017 Fuel Tech Report, p. 18.

\textsuperscript{17} 2017 Fuel Tech Report, p. 21.
down to a level closer to 135 ppm for the 24 hour block average and from 145 down to a level of 130 ppm for the 30-day averaging period.

As the optimization testing discussed in the 2017 Fuel Tech Report was of limited duration, it is my opinion that longer term testing performed using a more methodical approach would likely have shown the Wheelabrator facility’s ability to achieve the 130-135 ppm levels discussed above on a more consistent basis is possible right now. These tests would likely have shown the facility’s ability to achieve lower NOx levels on a longer term and more consistent basis if Wheelabrator had continued the adjustments made by Fuel Tech in June 2017 at each of its boilers with the express goal of achieving 130/135 ppm levels.

In addition, Wheelabrator should also have monitored and run all necessary feedback loops involving local NOx concentrations near the SNCR injection points, gas temperature in the SNCR injection plane, and ammonia slip. While Fuel Tech tested and showed the ability for automatic SNCR control to meet the 150 ppm setpoint, lower setpoints were not tested to explore the limits of the system. The use of automatic feedback controls at lower NOx setpoints should allow the SNCR system to consistently meet the lower 130/135 ppm levels on a longer term basis.

Wheelabrator should also have continued to optimize injector configurations and parameters as needed to achieve, maintain, and further reduce NOx at each of the boilers along the lines of the adjustments described in the conclusion of the 2017 Fuel Tech Report. Additional SNCR adjustments mentioned include using additional injectors, increasing total liquid flow to injectors, and changing the atomizing air pressure. The Fuel Tech test results indicate that even further NOx reduction may be possible, as the choice to decrease total liquid flow through each injector led to sub-optimal results in terms of NOx concentration, NOx reduction percentage and utilization percentage. Urea flow was also constrained to 20 gph, limiting the amount of information available on additional reduction and corresponding ammonia slip.

Importantly, it is clear to me that a limit of 135 ppm on a 24-hour basis and 130 ppm on a 30-day basis can be achieved now (and that more methodical optimization testing would have shown this to be the case) as opposed to the future dates in MDE’s proposed RACT – i.e., 2020 for the 145 ppm 30-day average and 2019 for the 150 ppm 24-hour block average.

**Performance Levels After the 2017 Fuel Tech Study**

I reviewed the 2017 hourly CEM NOx data for each unit to ascertain if Wheelabrator had attempted to conduct a long-term assessment of the optimization work, as recommended by Fuel Tech. Emails and data submitted to MDE by Wheelabrator show that Wheelabrator conducted longer-term testing from June 12-14, 2017 and June 20-29, 2017. However, this is still a relatively brief time period for such testing and my review
of the hourly data shows that the reductions achieved during the optimization periods were not sustained afterward. Also, the June 12-14, 2017 and June 20-29, 2017 data did not include additional important parameters such as ammonia slip, etc. which were discussed in the Fuel Tech Report covering the June 6-8, 2017 tests.

Shown below are the NOx levels, for each Unit:

- on the days of the optimization tests for that unit, including the initial testing date for each boiler and the subsequent dates (June 12-14 and 20-29, during which all boilers were tested);
- after the optimization tests (i.e., from June 30, 2017, the date on which all of optimization testing ended, until December 31, 2017, after the last day for which CEM data was available); and
- before the optimization testing (i.e., from January 1, 2017, till the day prior to the first optimization day for the respective unit).

<table>
<thead>
<tr>
<th>Unit</th>
<th>Average Hourly NOx (June 7, June 12-14, June 20-29, 2017), ppm</th>
<th>147.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1 Average Hourly NOx (June 30 - December 31, 2017), ppm</td>
<td>164.8</td>
<td></td>
</tr>
<tr>
<td>Unit 1 Average Hourly NOx (January 1 - June 6, 2017), ppm</td>
<td>158.1</td>
<td></td>
</tr>
</tbody>
</table>

| Unit 2 Average Hourly NOx (June 8, June 12-14, June 20-29, 2017 ), ppm | 148.1 |
| Unit 2 Average Hourly NOx (June 30 - December 31, 2017), ppm | 165.1 |
| Unit 2 Average Hourly NOx (January 1 - June 7, 2017), ppm | 168.6 |

| Unit 3 Average Hourly NOx (June 6, June 12-14, June 20-29, 2017), ppm | 144.9 |
| Unit 3 Average Hourly NOx (June 30 - December 31, 2017), ppm | 165.1 |
| Unit 3 Average Hourly NOx (January 1 - June 5, 2017), ppm | 167.6 |

It is clear, from Wheelabrator’s own CEM data presented above that the lower NOx levels achieved during the optimization were not sustained after the optimization dates at each unit. Arguably, for Unit 1, post-optimization average NOx (164.8 ppm) was worse than the pre-optimization level (158.1 ppm), which was higher than the 147.1 ppm for the optimization dates. For Unit 2, while the post-optimization level (165.1 ppm) was a little lower than the pre-optimization level (168.6 ppm), it was considerably higher than the 148.1 ppm for the optimization periods. Similarly, for Unit 3, the post-optimization level of 165.1 ppm was slightly lower than the pre-optimization level of 167.6, but much higher than the level for the optimization (144.9 ppm) periods.

It is clear that Wheelabrator did not continue to sustain the lower levels achieved during the 2017 Fuel Tech optimization study.
Conclusions

Based on my review of prior optimization work on its current SNCR systems including the 2017 Fuel Tech study and my analysis of the 2017 hourly NOx CEMS data for each Unit, I reach the following conclusions:

A. that each of the three units at the Wheelabrator facility can reasonably achieve hourly NOx levels of 150 ppm today, if the existing SNCR systems at each Unit, as modified per the suggestions and descriptions in the 2017 Fuel Tech Report, were properly implemented and operated;

B. that, therefore, 24-hour and 30-day averaged NOx levels of less than 150 ppm should also be achievable today. It is my opinion, based on the data that a 24-hour block level of 135 ppm should be achievable today and that a 30-day average level of 130 ppm should be achievable today at each Unit using optimized, existing SNCR;

C. that, based on the observed NOx levels reported by Wheelabrator post-optimization via the NOx CEM at each Unit, it appears that Wheelabrator did not continue with the optimization of the existing SNCR systems as discussed in the 2017 Fuel Tech Report beyond June 29, 2017. This is consistent with there being no regulatory driver or requirement for Wheelabrator to do so;

D. that Wheelabrator should electronically report not just the hourly NOx (and SO2 and CO) hourly CEMS data are it is currently doing, but also the additional parameters that are listed in the Tables on Page 22 of the 2017 Fuel Tech Report; and, finally

E. notwithstanding all of the above pertaining to the interim NOx levels that can be obtained via the proper and optimized operation of the existing SNCR systems to meet the proposed RACT – it is my opinion, based on my understanding of the boilers at the facility, that I see no technical impediments to the implementation of the even-more NOx reducing technologies, such as SCR (or hybrid SNCR/SCR), in the appropriate locations along the gas paths at each of the boilers. SCR would provide significantly better NOx levels (around 50 ppm, assuming roughly 75% SCR NOx reduction efficiency, a lenient target), than compared to optimized SNCR at 130-135 ppm as noted above.
ATTACHMENT A

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 refiners, 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-NOx ceramic radiant burners, fired heater NOx 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


"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.


U.C. Riverside, Extension


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


Loyola Marymount University


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


“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.


University of California, Los Angeles


International Programs

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

“Environmental Planning and Management,” IEP, UCR, Spring 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.


PUBLICATIONS (PARTIAL LIST)

"Physical Properties and Oxidation Rates of Chars from Bituminous Coals," with Y.A. Levendis, R.C.

"Char Combustion: Measurement and Analysis of Particle Temperature Histories," with R.C. Flagan,

(1988).

(1989).

"Post-Ignition Transients in the Combustion of Single Char Particles," with Y.A. Levendis, R.C. Flagan

"A Model for Single Particle Combustion of Bituminous Coal Char." Proc. ASME National Heat

"Discrete Simulation of Cenospheric Coal-Char Combustion," with R.C. Flagan and G.R. Gavalas,


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


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


PRESENTATIONS (PARTIAL LIST)


"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).


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.


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.


9. Affidavits and deposition on behalf of Basic Management Inc. (BMI) Companies in connection with the BMI vs. USA remediation cost recovery Case.


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.


15. Affidavit (July 2007) Comments on the Big Cajun I Draft Permit on behalf of the Sierra Club – submitted to the Louisiana DEQ.


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.


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.


23. Declaration (August 2008) on behalf of the Sierra Club in the matter of Dominion Wise County plant MACT.us


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.


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.


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

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).


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.


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.


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).


ExxonMobil Corporation et al., Civil Action No. 4:10-cv-4969 (Southern District of Texas, Houston Division).


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, 261st Judicial District).


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.


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.


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).


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.


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).


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).


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.


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.

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.


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).


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).


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.

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

114. 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.

115. Trial Testimony (February 2002) on behalf of Rocky Mountain Steel Mills, Inc. in Denver District Court.


119. 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.

120. 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.

121. Oral Testimony (October 2007) on behalf of the Sierra Club re. the Sevier Power Plant before the Utah Air Quality Board.


123. 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.

124. 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.


126. Deposition (October 2009) on behalf of Environmental Defense and others, in the matter of challenges to the proposed Coleto Creek coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH).
127. 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).

128. 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.

129. 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).


131. 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 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).


138. 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.
139. 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.

140. 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).

141. 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.).

142. 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).

143. 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).

144. 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.


147. 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 (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).

152. 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).


154. 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. 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. 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.

163. 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.

164. 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).

165. 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.

166. 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.

167. 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.

168. 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.

169. 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).
170. 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).


173. 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).