

# **On the Stingency of Proposed Phase 2 NO<sub>x</sub> Controls for Coal-Fired Electric Generating Units**

by

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

## **A. Description of project**

I was asked to evaluate the stringency of the proposed Phase 2 NO<sub>x</sub> emission limits for coal-fired electric generating units set forth in 22a-174-22e(d)(2)(C) in light of the stringency of alternative compliance options and case-by-case RACT requirements in 22a-174-22e(g) and (h). To my knowledge, Bridgeport Unit 3 is the only coal-fired boiler serving an electric generating unit that would be subject to the emission limitations set forth in 22a-174-22e(d)(2)(C). Consequently, my review focused on this unit.

## **B. Description of the Affected Unit and Current NO<sub>x</sub> Controls**

Bridgeport Unit 3 is a coal-fired electric utility generator with a nameplate capacity of 410 MW,<sup>2</sup> with a maximum hourly heat input rate of 4,100 MMBtu/hr.<sup>3</sup> As such, it meets the definition of an “affected unit” under Section 22a-174-22e(a).

Bridgeport Unit 3 was initially constructed as a coal unit in 1968. Following conversion to oil burning in the 1970’s, it was reconverted to coal firing in 1984. Pertinent to its NO<sub>x</sub> emissions, “During the reversion to coal firing in 1984, close-coupled overfire air was added.”<sup>4</sup>

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

<sup>2</sup> Title V Permit 015-0217-TV, Issued October 2012, page 7 of 75. The rating of Unit 3 has been variously reported as 390 MW (see Buffa paper, circa 1995), 400 MW (see Romero paper, circa 2005), and 410 MW. I use the 410 MW value as depicted in its most recent permit.

<sup>3</sup> Application for Title V Permit, February 2011, pdf p. 305.

<sup>4</sup> Buffa, T., et. al., In Furnace Retrofit Ultra-low NO<sub>x</sub> Control Technology for Tangential, Coal-fired Boilers: The ABS C-E Services TFS 2000R System, EPRI/EPA 1995 Joint Symposium on Stationary Combustion NO<sub>x</sub> Control, May 1995. Provided in Attachment C.

While the coal burned in this unit for most of its operating history was Eastern US low-sulfur coals, currently low-sulfur coals foreign coals are burned in this unit.<sup>5</sup> These coals are generally similar to US sub-bituminous coals.<sup>6</sup>

Combustion and NO<sub>x</sub> optimization for this unit are described in a more recent paper as follows:

“[B]ridgeport Unit 3 is a 400 MW tangentially-fired, four-corner subcritical single-reheat unit that was converted to burn a variety of low-sulfur coals and retrofitted with a CE TFS2000R low-NO<sub>x</sub> firing system. The low-NO<sub>x</sub> system consists of three levels of tiltable and yawable upper SOFA registers (Levels A, B and C), three levels of tiltable and yawable lower SOFA registers (Levels A, B and C), two levels of CCOFA registers (Levels A and B), and five elevations (A to E) of low-NO<sub>x</sub> burners.

The combustion system utilizes a combination of staged combustion, blanket offset air and over-fire air to reduce NO<sub>x</sub>. Under staged combustion, a portion of the secondary air is diverted away from the main burner zone to the CCOFA and SOFA ports located above the main windbox. The concentric secondary air (SA) compartments in each furnace corner utilize blanket air that permits SA to be diverted away from the coal stream. This enhances air staging for NO<sub>x</sub> control. In addition, a blanket of air along the furnace walls is created that provides an oxidizing environment next to the waterwalls. All SA registers and burner nozzles in the main windbox can be tilted 30 degrees above or below horizontal position.

Coal to the burners is supplied by five exhauster type pulverizers (A to E), where A is the top mill, feeding the top burner elevation, and E is the bottom mill, feeding the bottom burner elevation. The excess O<sub>2</sub> level is measured by six O<sub>2</sub> probes located in two economizer gas exit ducts (three probes per duct).

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The unit complies with emission limits by firing an imported coal, characterized by a low heating value (HHV), low Hardgrove grindability index (HGI), high moisture content, low ash content, low nitrogen, high ash iron content, and low ash softening temperature.

The unit is equipped with a SO<sub>3</sub> flue gas conditioning (FGC) system which injects SO<sub>3</sub> the air preheater (APH) inlet to improve ESP performance. Furnace is

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<sup>5</sup> For example, as reported to the US Department of Energy, Energy Information Administration (EIA), via Form 923,(see <http://www.eia.gov/electricity/data/eia923/>) . The fuel supplier is listed as Adaro, and the coal mine supplying the coal for this unit is listed as Tutupan. This mine is located in South Kalimantan, Indonesia.

<sup>6</sup> The coal burned in this unit is noted as sub-bituminous in the EIA annual filings.

cleaned by 48 wallblowers, arranged in 3 elevations, while 18 retractable sootblowers are employed to clean convection pass of the boiler.”<sup>7</sup>

In addition to the above, it is also possible that combustion optimization, which was implemented at the unit around 2005 is still being used at the unit to manage NO<sub>x</sub> and CO emissions.<sup>8</sup>

As such, given the combustion controls for NO<sub>x</sub> already present at the unit, i.e., low-NO<sub>x</sub> burners and over-fire air, further NO<sub>x</sub> reductions can only be achieved by post-combustion NO<sub>x</sub> control technologies such as Selective Non-Catalytic Reduction (SNCR) or Selective Catalytic Reduction (SCR). After a brief discussion of the current or baseline NO<sub>x</sub> emissions from this unit, I discuss both SNCR and SCR as they might apply to this unit.

### **C. Current/Baseline NO<sub>x</sub> Emissions**

The hourly NO<sub>x</sub> emissions from Unit 3 are available from the EPA’s Acid Rain Database at [www.epa.gov/ampd](http://www.epa.gov/ampd). A review of these hourly emissions for the period January 2012 – June 30, 2015 (the most recent 3.5 year period, covering a range of economic conditions) shows that the 50<sup>th</sup> and 95<sup>th</sup> percentile values of the actual hourly NO<sub>x</sub> emissions for this time period are 0.135 and 0.157 lb/MMBtu, respectively. As I will discuss later, I will use the 95<sup>th</sup> percentile value of the actual hourly emissions as an upper bound, yet stable indicator for the baseline NO<sub>x</sub> emissions for this unit as well as for comparisons to future NO<sub>x</sub> emissions levels with various controls. I will also use the 50<sup>th</sup> percentile values as an indicator of the “average” conditions.

### **D. Evaluation of SNCR and SCR for Unit 3**

As far as NO<sub>x</sub> emissions controls, as discussed above, Unit 3 has low-NO<sub>x</sub> burners (LNB) and separated over-fire air (SOFA). It does not have advanced controls such as Selective Non-

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<sup>7</sup> Romero, C. E. et. al., Comprehensive Approach to Performance Improvement and Emissions Reduction on a 400 MW Tangentially-Fired Boiler: Part 1 – Combustion Optimization, Prepared for Presentation at the 30th International Technical Conference on Coal Utilization and Fuel Systems, April 2005, Clearwater, Florida. Provided in Attachment C.

<sup>8</sup> *Ibid.*

Catalytic Reduction (SNCR) or Selective Catalytic Reduction (SCR).<sup>9</sup> SNCR relies on gas-phase reduction reactions to convert NO<sub>x</sub> back to nitrogen. As such, it is very sensitive to the temperature of the gas stream<sup>10</sup> where the reducing agent (typically ammonia or urea) is added, as well as inlet NO<sub>x</sub> levels, among other conditions. SCR, on the other hand, relies on reactions that occur on a fixed catalyst bed that is put in the gas path to reduce NO<sub>x</sub> back to nitrogen. SCR is the more expensive but more robust and more effective of the two controls.

I have evaluated the effect that addition of SNCR and SCR would have on the NO<sub>x</sub> emissions from Unit 3.

### ***D.1 Evaluation of SNCR***

First, it is my opinion that the addition of SNCR will not reduce NO<sub>x</sub> emissions from this unit by a substantial amount or to levels consistent with reduction levels identified as compliance alternatives in Section 22a-174-22e(g).

As a recent technical analysis by EPA notes:

“[R]eported SNCR reduction efficiencies vary over a wide range. Temperature, residence time, type of NO<sub>x</sub> reducing reagent, reagent injection rate, uncontrolled NO<sub>x</sub> level, distribution of the reagent in the flue gas, and CO and O<sub>2</sub> concentrations all affect the reduction efficiency of the SNCR (internal citations omitted).”<sup>11</sup>

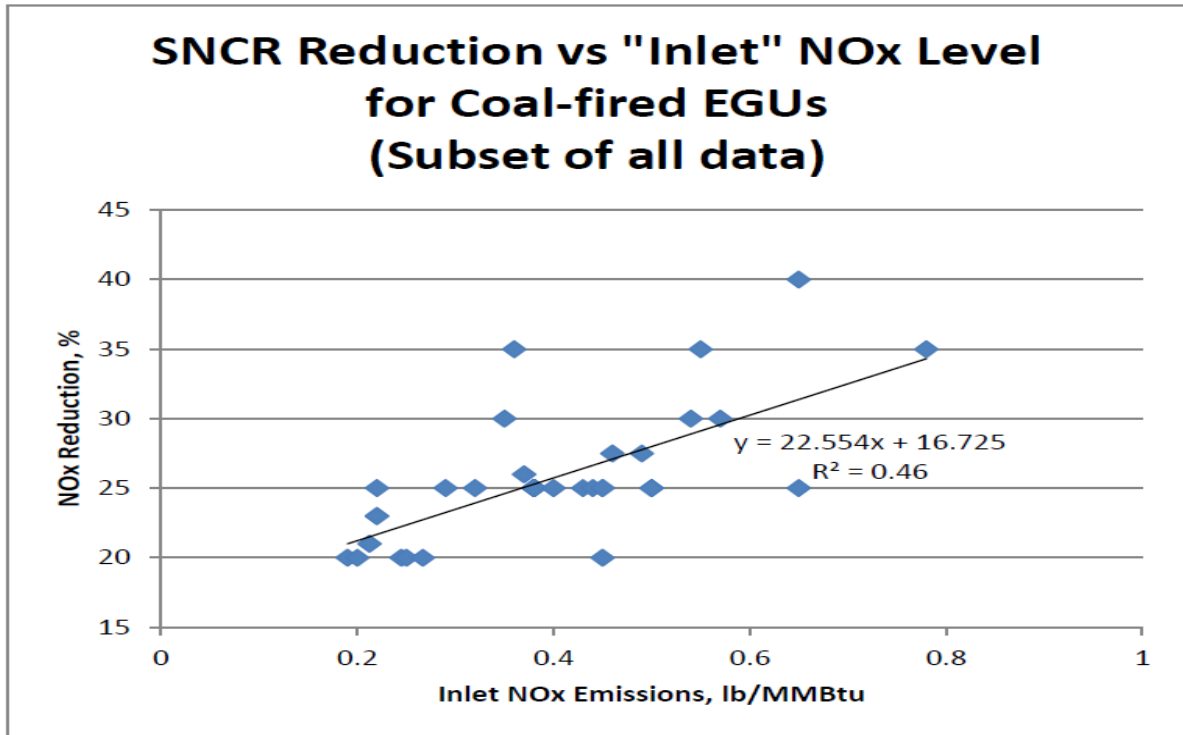
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<sup>9</sup> More precisely, I evaluated high-temperature SCR, the more common implementation of this technology, in which the SCR catalyst is typically installed after the economizer but before the air pre-heater in a coal-fired unit. While there are low-temperature SCR catalysts also available, and these are installed in the gases just prior to their introduction into the smoke stack, their use is not significant in the US coal fleet.

<sup>10</sup> SNCR is only effective if the reducing agent is added to the exhaust gases containing NO<sub>x</sub> within a relatively narrow temperature “window,” typically between 1600 F and 2100 F.

<sup>11</sup> See [http://www3.epa.gov/ttnecas1/models/SNCRCostManualchapter\\_Draftforpubliccomment-6-5-2015.pdf](http://www3.epa.gov/ttnecas1/models/SNCRCostManualchapter_Draftforpubliccomment-6-5-2015.pdf). Page 1-3.

In particular, EPA notes that the median NO<sub>x</sub> reduction for SNCR for coal-fired boilers is 25%.<sup>12</sup> More importantly, EPA discusses the relationship between “inlet” NO<sub>x</sub> levels and SNCR efficiency for coal-fired boilers. The figure below shows the relationship.



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Using the 50<sup>th</sup> percentile NO<sub>x</sub> baseline of 0.135 lb/MMBtu and the regression equation provided in the figure above, I obtain a NO<sub>x</sub> reduction efficiency of 19.8%. Using the 95<sup>th</sup> percentile NO<sub>x</sub> baseline value of 0.157 lb/MMBtu, the estimated SNCR efficiency is 20.3%.

These estimated NO<sub>x</sub> removal efficiencies of approximately 20% for installation and operation of SNCR would not qualify as a compliance option for Phase 1 or Phase 2 under the compliance options identified in the regulation in section 22a-174-22e(g)(2), which requires a minimum of 40% reduction of NO<sub>x</sub> from either 2014 or 2019 baselines. Based on my familiarity with the technical specifications of this unit and the capabilities of SNCR as discussed above, it is my

<sup>12</sup> *Ibid*, Table 1-1, page 1-4.

<sup>13</sup> *Ibid*, Figure 1.1c, page 1-6.

opinion that it would be almost impossible for SNCR at this unit to provide a minimum of 40% reduction from its current (i.e., 2014) and expected future (i.e., 2019) baseline NO<sub>x</sub> levels, assuming that the 2019 NO<sub>x</sub> levels are generally maintained at current levels and are not dramatically greater than NO<sub>x</sub> levels today. As the figure from EPA provided earlier shows, baseline NO<sub>x</sub> levels would have to be around 1 lb/MMBtu (or around 6-7 times higher than currently) to obtain 40% NO<sub>x</sub> reduction.

## ***D.2 Evaluation of SCR***

I also evaluated SCR against the cost-effectiveness criteria set forth in 22a-174-22e(h). Like SNCR, SCR has a temperature limitation in that the gas temperature is typically required to be above a threshold temperature (typically called a minimum operating temperature or MOT) in order to properly effect the reduction reactions in the catalyst and also in order to not adversely impact the catalyst due to condensation of impurities, particularly condensable sulfur compounds. I note that due to its burning low sulfur coal, such condensables should be low at Unit 3, leading to a lower MOT than at many SCRs that currently operated in the US coal fleet burning high-sulfur coals.

To account for the MOT, I assumed that SCR would not be effective until a threshold load was reached at Unit 3 – typically 30%. Once this minimum load is achieved, however, SCR NO<sub>x</sub> reduction efficiencies can be very high, ranging as high as 90% or greater, for the types of baseline NO<sub>x</sub> levels currently being achieved at Unit 3.<sup>14</sup> In reality, once SCR is installed, the operator has the ability to effect an overall NO<sub>x</sub> removal strategy that optimizes the amount of NO<sub>x</sub> creation/reduction in the boiler along with additional NO<sub>x</sub> reduction in the SCR – so that overall emissions of NO<sub>x</sub> and CO are optimized along with optimization of process variables such as loss on ignition (LOI).

To be conservative, I assumed SCR efficiencies to vary between 75% and 90%. Even so, my calculations show that the 95<sup>th</sup> percentile hourly NO<sub>x</sub> emissions, with SCR would be in the range of 0.075 to 0.10 lb/MMBtu. The corresponding 50<sup>th</sup> percentile hourly NO<sub>x</sub> emissions would be

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<sup>14</sup> I note that SCR catalyst vendors have offered NO<sub>x</sub> reductions greater than 90% in many instances. I use 90% as a conservative estimate for this analysis.

in the range 0.014 to 0.035 lb/MMBtu. While the 95<sup>th</sup> percentile values are much higher than what coal units are able to achieve today with SCRs (NO<sub>x</sub> levels down to below 0.05 lb/MMBtu are not uncommon), the 50<sup>th</sup> percentile values are in the range of what is being achieved by SCR units today in the US coal fleet. Thus, I feel that SCR would provide substantial reductions as compared to baseline NO<sub>x</sub> levels being currently achieved at Unit 3 presently.

I evaluated the cost-effectiveness of SCR in \$/ton NO<sub>x</sub> reduced as required in Section 22a-174-22e(h)(5)(E), following the approach prescribed in Section 22a-174-22e(h)(5)(D). Consistent with this section, “[C]ost shall be evaluated on an annualized full load basis (8,760 hours/year) unless the hours of operation of the emission unit are subject to a practicably enforceable limitation...”. I did not find any practicably enforceable limitation of hours of unit operation in the Title V permit for Unit 3. Therefore, I used 8,760 hours of operation at full load as required by the regulation.

In doing the cost-effectiveness calculations, I followed standard EPA cost-effectiveness procedures, as provided in Attachment B to this report. I first used the range of 95<sup>th</sup> percentile outlet NO<sub>x</sub> emissions (0.10 to 0.075 lb/MMBtu) and the 95<sup>th</sup> percentile baseline inlet NO<sub>x</sub> emissions (0.157 lb/MMBtu) for these calculations. Even though these calculations are generally designed to be conservative – i.e., over-predict the cost-effectiveness – the calculated cost-effectiveness values ranged from \$7,757 to \$10,078 per ton of NO<sub>x</sub> reduced. I also used the 50<sup>th</sup> percentile values of baseline and predicted NO<sub>x</sub> outlet levels with SCR. Using these, I obtained a cost-effectiveness range of \$5,971 to 6,847 per ton of NO<sub>x</sub> reduced.

All of the calculated cost-effectiveness values above are well below the value of Phase 2 cost-effectiveness deemed acceptable per the regulation as provided in 22a-174-22e(h)(1)(A)(iii): “[F]or the purposes of this subsection, economic feasibility is determined on a dollar/ton basis, where any determined value equal to or less than \$13,118/ton NO<sub>x</sub> for a Phase 1 determination or \$13,635/ton NO<sub>x</sub> for a Phase 2 determination is presumed economically feasible.”

Thus, I conclude that SCR is the appropriate post-combustion NO<sub>x</sub> reduction technology for Unit 3 to meet the Phase 2 requirements of the regulation.

**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 five 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 three 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.

Specific to mobile source as well as non-road engine, equipment, and emissions testing, based on his education (Mechanical Engineer, with B.Tech, M.S. and Ph.D) and over two decades of consulting experience for a wide range of clients including trade associates (consisting of equipment manufacturers of lawn and garden, marine, snow, as well as major US and global on-road vehicle manufacturers), Dr. Sahu is very familiar with engine, fuel systems, and air pollution control technologies: for HC+NO<sub>x</sub> and CO for spark-ignited; and for NO<sub>x</sub> and PM for compression ignition (i.e., diesel) engines. Second, he is very familiar with relevant EPA (and CARB) testing and regulatory aspects pertaining to non-road and mobile engines and vehicles, including relevant Federal regulations pertaining to diesel emissions testing and test procedures and standards in non-road as well as on-road applications including heavy duty highway engines (40 CFR Part 1065 and relevant portions of 40 CFR Part 86, Subparts A and N), marine diesel engines (40 CFR Part 1065 and 40 CFR Part 94) and locomotives (40 CFR Part 1065 and 40 CFR Part 92 as well as other non-road engines (40 CFR Part 89). His familiarity extends to various testing and standards regulations in spark-ignited non-road engines including recreational vehicles, marine engines, lawn and garden engines, as well as construction equipment engines (40 CFR Part 1065) and to vehicle testing requirements and test procedures in 40 CFR Part 80, 40 CFR Part 86, 40 CFR Part 87, 40 CFR Part 90, 40 CFR Part 1033, 40 CFR Part 1039, 40 CFR 1042, 40 CR Part 1045, 40 CFR Part 1051, 40 CFR Part 1060, 40 CFR Part 1065 and 40 CFR Part 1066. Lastly he is familiar with a wide variety of Federal, California, European, and Japanese dynamometer driving schedules.

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

"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

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

- (a) 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.”

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

- (b) 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.
- (c) 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).
- (d) 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).
- (e) 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).
- (f) 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).
- (g) 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.
- (h) 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).
- (i) Affidavits and deposition on behalf of Basic Management Inc. (BMI) Companies in connection with the BMI vs. USA remediation cost recovery Case.
- (j) Expert Report on behalf of Penn Future and others in the Cambria Coke plant permit challenge in Pennsylvania.
- (k) 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.

- (l) 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.
- (m) 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.
- (n) 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).
- (o) Affidavit (July 2007) Comments on the Big Cajun I Draft Permit on behalf of the Sierra Club – submitted to the Louisiana DEQ.
- (p) 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).
- (q) Expert Reports and Pre-filed Testimony before the Utah Air Quality Board on behalf of Sierra Club in the Sevier Power Plant permit challenge.
- (r) 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) .
- (s) 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.
- (t) 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.
- (u) 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).
- (v) 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).
- (w) Declaration (August 2008) on behalf of the Sierra Club in the matter of Dominion Wise County plant MACT.us

- (x) Expert Report (June 2008) on behalf of Sierra Club for the Green Energy Resource Recovery Project, MACT Analysis.
- (y) 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.
- (z) 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.*
- (aa) 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).
- (bb) 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.
- (cc) 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).
- (dd) 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.
- (ee) 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).
- (ff) 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).
- (gg) 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.
- (hh) 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.
- (ii) 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).
- (jj) 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.

- (kk) 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).
- (ll) 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).
- (mm) 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).
- (nn) 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).
- (oo) 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.
- (pp) 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.
- (qq) 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).
- (rr) 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).
- (ss) 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.
- (tt) 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).
- (uu) 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).

- (vv) 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.
- (ww) 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).
- (xx) 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).
- (yy) 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).
- (zz) 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).
- (aaa) 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).
- (bbb) 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).
- (ccc) 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).
- (ddd) 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).
- (eee) 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).
- (fff) Declaration (April 2012) in the matter of the EPA's EGU MATS Rule, on behalf of the Environmental Integrity Project.

- (ggg) 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.
- (hhh) 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.
- (iii) 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.
- (jjj) 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.
- (kkk) 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.
- (lll) 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.
- (mmm) 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.
- (nnn) 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).
- (ooo) 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).
- (ppp) 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).
- (qqq) 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.
- (rrr) 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.

- (sss) 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.
- (ttt) 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).
- (uuu) 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.
- (vvv) 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).
- (www) 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).
- (xxx) 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).
- (yyy) 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).
- (zzz) 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).
- (aaaa) 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).
- (bbbb) 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).
- (cccc) 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).

- (dddd) 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).
- (eeee) Pre-filed Direct Testimony (March 2015) and Rebuttal Testimony (August 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.
- (ffff) Expert Report (March 2015) 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).
- (gggg) 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).
- (hhhh) 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).
- (iiii) 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,” *White Stallion Energy Center, LLC v. US EPA*, Case No. 12-1100 (US Court of Appeals for the District of Columbia).

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

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

- (llll) 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).
- (mmmm) 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).
- (nnnn) 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).
- (oooo) 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.
- (pppp) 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.
- (qqqq) Oral Testimony (October 2007) on behalf of the Sierra Club re. the Sevier Power Plant before the Utah Air Quality Board.
- (rrrr) 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.
- (ssss) 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.
- (tttt) 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.
- (uuuu) 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.*
- (vvvv) 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).
- (wwww) 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).
- (xxxx) 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.
- (yyyy) 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).
- (zzzz) 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.

- (aaaaa) 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).
- (bbbbb) 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.
- (ccccc) 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).
- (ddddd) 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).
- (eeeee) 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).
- (fffff) 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.
- (ggggg) 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.
- (hhhhh) 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.
- (iiiiii) 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.
- (jjjjj) 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).
- (kkkkk) 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.).
- (lllll) 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).

- (mmmmm) 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).
- (nnnnn) 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.
- (ooooo) 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).
- (ppppp) 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).
- (qqqqq) 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.
- (rrrrr) 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.
- (sssss) 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).
- (ttttt) 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).
- (uuuuu) 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).
- (vvvvv) 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).
- (wwwww) 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).
- (xxxxx) 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).



- (yyyyy) 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).
- (zzzzz) 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).
- (aaaaaa) 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).
- (bbbbbb) 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.
- (ccccc) 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).
- (dddddd) 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).

**Attachment B**

**SCR Cost Effectiveness Calculations (Spreadsheet)**

**Attachment C**

**Copies of Buffa et. al., and Romero et. al., Papers**