

Utah Sustainable Transportation and Energy Program (STEP)

Clean Coal Research Projects

Applications of Neural Net Optimization Tools



STEP Clean Coal Technology Research Program

- Mission
 - SB115-54-20-104: ...**a program to investigate, analyze, and research clean coal technology**”
- Budget
 - An average of \$1 million per year over a five year period for the clean coal technology program (\$5 million total)

Preferences, Objectives and Requirements

- Preferences:
 - Technology demonstrations (hardware)
 - Advance existing technology
 - Utah centric
 - Leverage available funding (US DOE, state, local)
- Objectives:
 - Benefits customers, technology/commercialization advancement and emissions improvements
- Requirements: expenditures need to be prudent

STEP Process to Engage Stakeholders

- Compiled Clean Coal Research team consisting of: Huntington & Hunter plant personnel, Technical Services, Utah university academia: Chem. Eng./Mech. Eng. (BYU, USU, UofU), Utah Office of Energy Development, USTAR, UofU Earth Geosciences Institute, Reaction Engineering and Sustainable Energy Solutions
- Multiple workshops/locations
- Identified key *Areas of Research* in the areas of CO₂ capture and sequestration and NO_x emissions control
- NO_x control webinars (<http://home.mcilvainecompany.com/>)
“Power Plant Air Quality Decisions”

NOx Emission Controls

Areas of Interest

1. Neural net controls (demo) – Huntington Unit 2
2. Advanced combustion controls, Selective Non-Catalytic Reduction (SNCR), NOx scrubbing; objective: utility scale demonstration

Huntington Plant



Neural Network Optimization Objectives

- Neural network software will “learn” plant characteristics from sensor data
- Continuously evaluates input data and implements plant settings for optimal performance
- Heat rate improvements by up to 1.5% ^[1]
- NOx emissions reductions of up to 48% ^[2]
- Emissions improvements with no major capital costs – sensors and software only

^[1] Rambalee P, Gous G, de Villiers PG., McCulloch N, Humphries G. Control and Stabilization of a Multiple Boiler Plant: An APC Approach. IFAC Proc Vol 2010;43:109–14. doi:10.3182/20100802-3-ZA-2014.00027.

^[2] Sargent & Lundy LLC. Report to EPA: Coal-Fired Power Plant Heat Rate Reductions. 2009.

Best Operator

- Neural network strives to create an experienced optimal operator that can make decisions 24/7

This



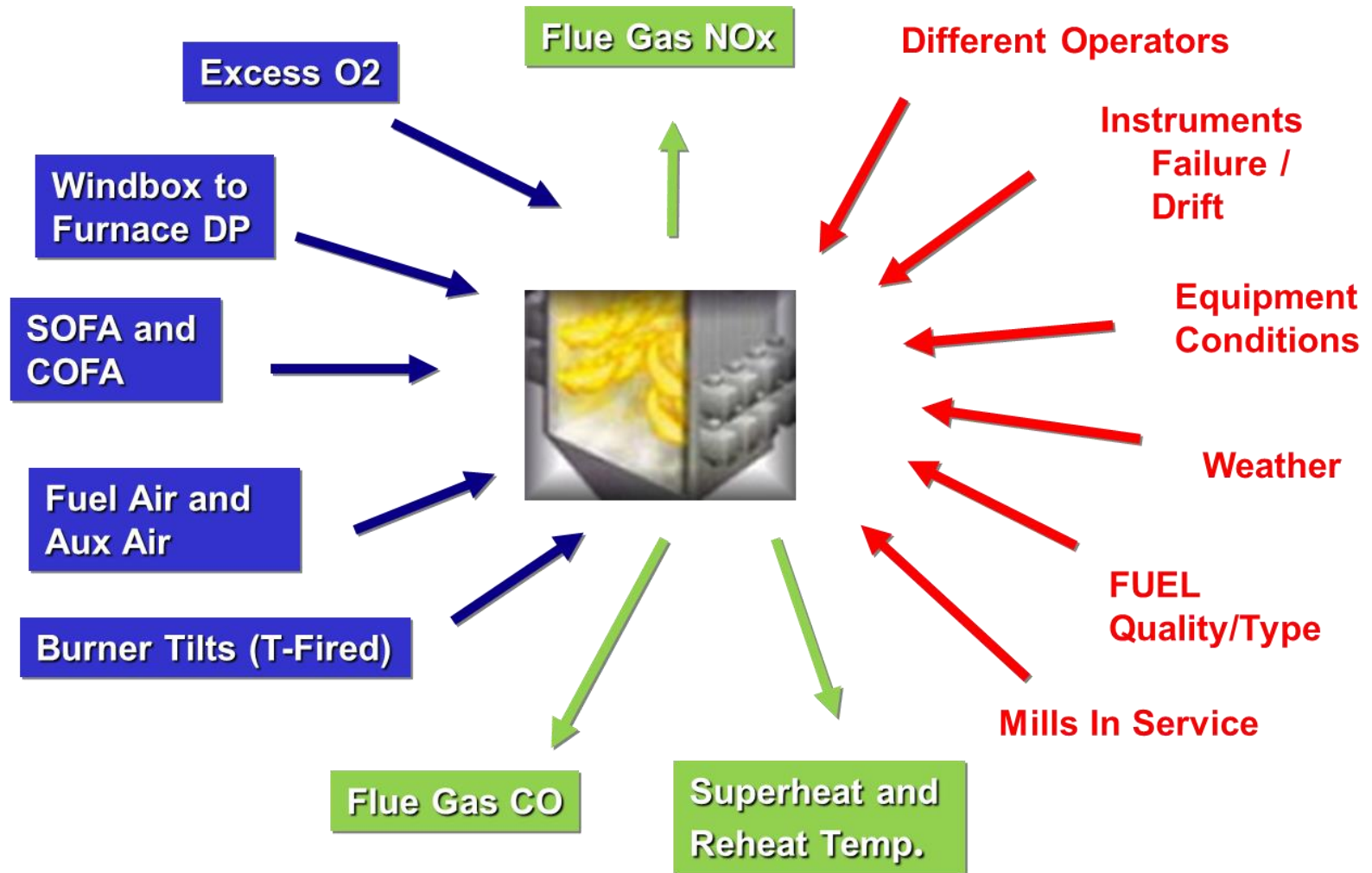
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NOx Emission Controls – Neural Nets

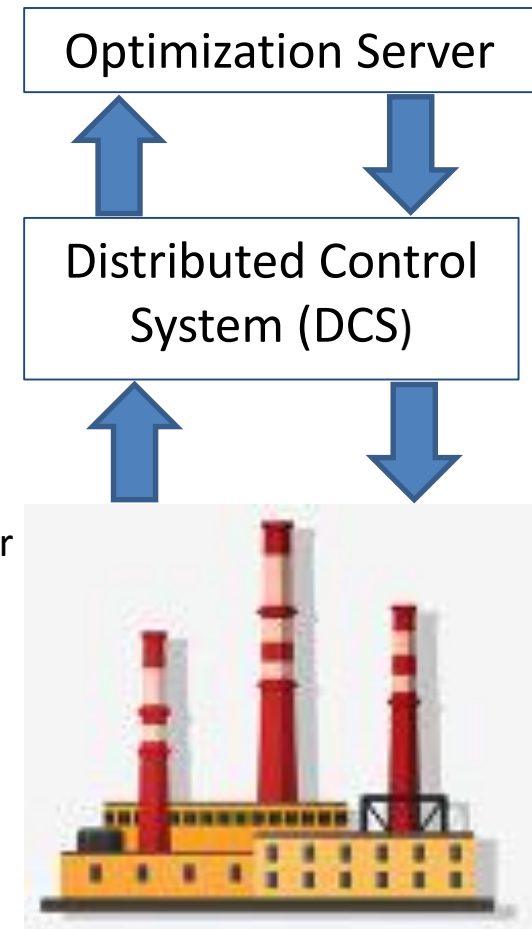
- Why is a neural network model desirable for a process as complex as coal combustion?
- How does real-time optimization work?
- What aspects of this project are research?
 - optimizing under constantly changing conditions - most notably frequent and drastic load changes;
 - use of University of Utah engineering students;
 - ownership and adaptability of a software package as opposed to a service

Why Combustion Optimization?

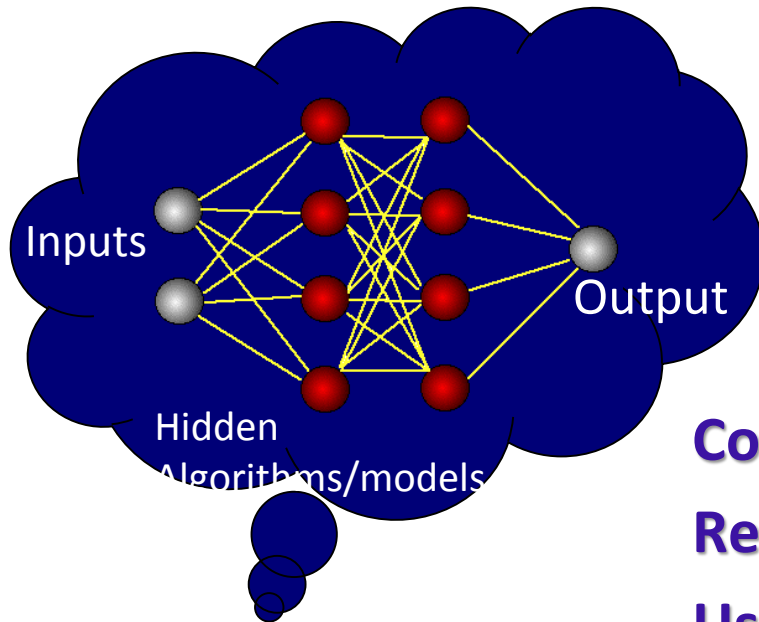


How Real-Time Optimization Works

- The unit data (temperatures, pressures, flow rates, etc.) are collected by the Digital Control System
- Data is then fed to a server that contains a mathematical model of the unit
 - The model is used to make predictions of outputs (e.g., NO_x emissions or heat rate) from the given inputs
- The mathematical model is first reconciled to the unit data to ensure accuracy
 - The model continually “learns” the unit’s behavior under changing conditions (coal quality, load changes, etc.)
- The model is then solved for optimal conditions
 - Objective can be to minimize NO_x or to maximize efficiency (or a combination)
- Optimal set points are then sent to the unit
 - The unit should go to its optimal state
- The process is repeated at regular intervals (~15 min to 1 hour) on a rolling basis so the model stays accurate and the unit maintains its optimal condition



How Real-Time Optimization Works



Collects/Cleans Data

Retrains Models

Uses Models for Optimization

Computes Bias Setting

Fuzzy Control for other Bias Settings

NOx Emission Controls

Neural Net Controls - Objectives

- Develop and install neural net software at Huntington Unit 2 (also applicable to sister units at Hunter plant)
- Benefit/Objectives:
 - 1st: NOx emissions reductions (target~20+% achievable?)
 - 2nd: heat rate (CO₂) reductions (boiler efficiency) (~0.5%?)
 - 3rd: other plant processes (i.e. FGD system, fan controls)
- Implementation schedule to be aligned with instrumentation upgrades (coal flow, O₂, CO, & furnace exit gas temperature monitors)
- Project design based on draft submittal from University of Utah; lead investigator: Dr. Kody Powell.

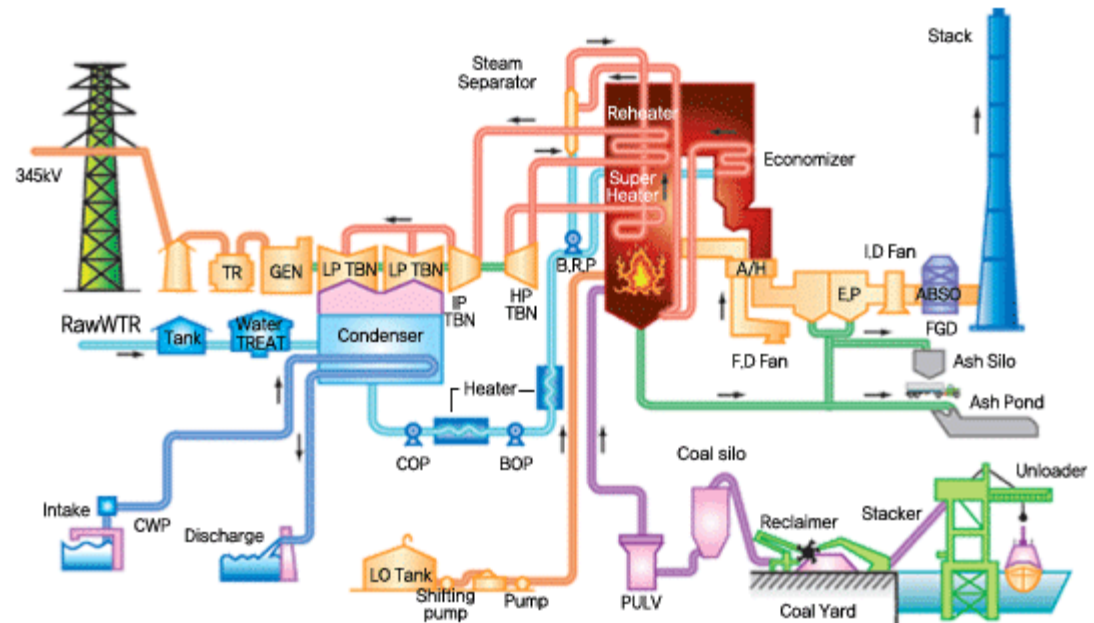
Neural Net Controls

Research Objectives

- **Study impact of neural network combustion optimization at Huntington 2**
 - System installation
 - Provide plant personnel training
 - Parametric studies to identify key factors
 - Ongoing technical support
 - Continually work to improve system and functionality
 - Document benefits (environmental and economical)
- **Explore opportunities for dynamic real-time optimization under ramping conditions**
 - Enhanced unit flexibility will better enable renewables integration
- **Explore benefits of applying neural network optimization to auxiliary systems**
 - Cooling water system
 - Scrubbers

Research Objective: Optimizing Auxiliary Systems

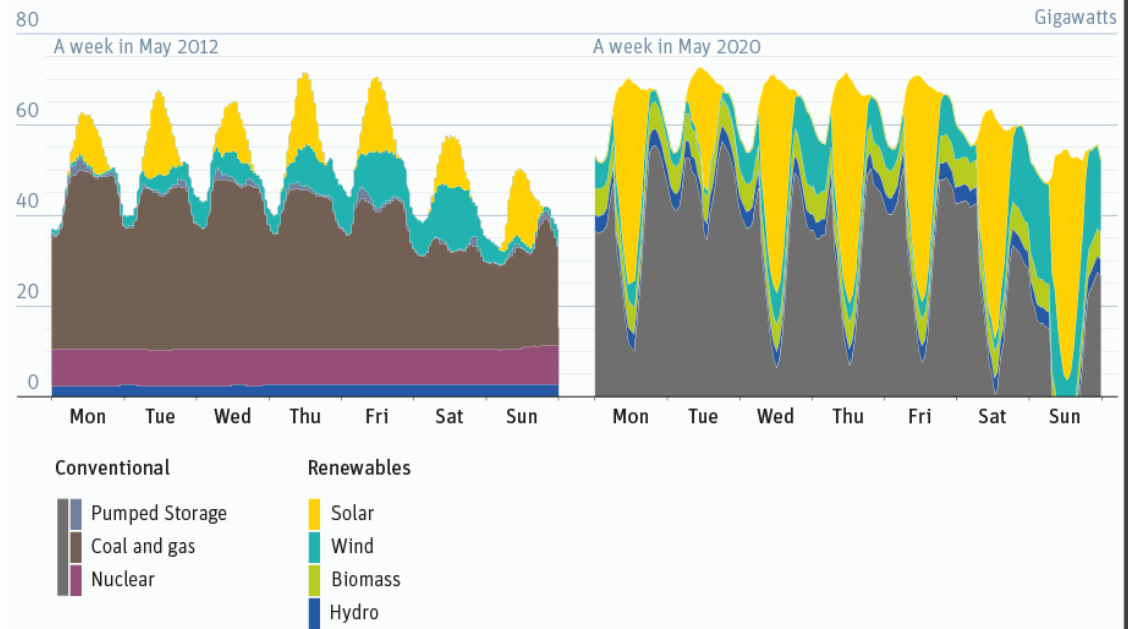
- Primary objective is to optimize the combustion process
- If successful, optimization may be applied to additional systems
- Opportunity to save energy and reduce emissions
- Potential for R&D and future cost savings



<https://www.quora.com/How-is-energy-created-in-a-coal-power-plant>

Research Objective: Dynamic Optimization of Power Plant with Frequent Ramping

- Integration of renewables requires flexible operation
- Difficult to optimize with a moving target
- Dynamic optimization takes into account forecasted conditions and optimizes over a time horizon, not just for “now”
- Challenging research problem



Bertram R. Renewables Need Flexible Backup, Not Baseload. Energy Transit 2015.

NOx Emission Controls – Neural Net Project Team

- PacifiCorp (Huntington & Hunter plants, Corporate Technical Services, Resource Development)
 - Project management & procurement
 - Installation
 - Operation
 - Monitoring & reporting
- University of Utah
 - Software application
 - Updates
 - Operator training
- Taber International/Griffin
 - Software
 - Initial setup and training

NOx Emission Controls – Neural Nets

- How can better instrumentation help?
 - CO, O₂ Temperature Grid - Allows for quicker indication and response to boiler disturbances improving operations control and optimization of the combustion process.
 - Understanding what instrumentation works the best for neural optimization is part of this study.
- What have other plants accomplished?
 - Ameren Rush Island - PRB User's Group Plant of the Year 2016
 - "NOx emissions are managed by overfired air and a Griffin neural net combustion optimization system. The permit limit for NOx emissions is 0.40 lb/MMBtu, although actual average annual NOx emissions have remained below 0.10 lb/MMBtu over the past decade, without an SCR. For 2015, NOx emissions averaged 0.081 lb/MMBtu. Particulates are captured with an electrostatic precipitator on each unit (there is no baghouse)." - *Power Magazine* 07/01/2016 | Dr. Robert Peltier, PE

NOx Emission Controls – Neural Nets

- Why have applications of neural nets been challenging?
 - Buy-In/Acceptance/Training
 - Instrumentation
 - Control Output

Why is intelligent soot-blowing needed?

- Slagging prevention/furnace cleanliness/temperature balance

Sometimes it makes sense to break out different processes. In this case we are separating fuel air staging from furnace cleanliness. It is common for NNO vendors to separate these functions. We may eventually employ an optimizer for fuel preparation as well.

Summary

- Advantages of Optimization
 - No large capital costs required
 - Only requires instrumentation upgrades and software
 - Synergistic with other clean coal technologies
- Benefits for Huntington Unit 2
 - Easily scalable to other units
- Ideal combination of an upgrade project with research potential
 - Turnkey solution from an experienced vendor
 - Research dynamically optimizing under ramping conditions to enable renewables
 - Research application of optimization to auxiliary plant systems

Neural Net Applications - Budget

	Contracting Party	2017	2018	2019	2020	2021	Total
University of Utah							
UofU Staffing (with Overheads)	Contracted by Pcorp	\$ 90,985	\$ 92,805	\$ 94,661	\$ -	\$ -	\$ 278,451
Per Diem (with Overheads)		\$ 37,698	\$ 37,698	\$ 41,358	\$ -	\$ -	\$ 116,754
External Requirements							
External Consulting	Managed by PCorp	\$ 30,000	\$ 30,000	\$ 30,000	\$ -	\$ -	\$ 90,000
PC/Server	Purchase by PCorp	\$ 10,000					\$ 10,000
Taber							\$ -
Training	Purchase by PCorp	\$ 30,000					
Engineering Services	Purchase by PCorp	\$ 160,000	\$ -				\$ 160,000
Licensing Fees	Purchase by PCorp	\$ 160,000	\$ -	\$ 32,000	\$ 32,000	\$ 32,000	\$ 256,000
Taxes	Pcorp obligation	\$ 10,976	\$ -				\$ 10,976
Other							
Contingency (on labor/consulting)	Managed by PCorp	\$ 18,148	\$ 18,421	\$ 18,699	\$ -	\$ -	\$ 55,268
Total		\$ 547,806	\$ 178,924	\$ 216,719	\$ 32,000	\$ 32,000	\$1,007,449

Low NOx Technology Objectives

- Evaluate promising/emerging technologies that may result in NOx emissions that are similar to emissions from traditional Selective Catalytic Reduction (SCR) systems or can provide material, cost effective NOx emissions reductions
- If practicable, install a slipstream demonstration of the technology on one of the affected Hunter or Huntington units
- Company proposes to use an RFI/RFP process to solicit formal technical and commercial proposals to identify viable technology prospects
- Company recognizes that to achieve significant reductions may require a combination of one or more technologies (such as additional combustion modifications combined with subsequent NOx reduction technologies)

Low NOx Technologies

Summary of Key Technology Presentations

- Combustion modifications
- FuelTech/RV Industries
- AECOM -RotaMix & LowTox
- APCS – PeroxyChem
- GORE & FLSmidth - Catalytic Fabric Filter Bags

Low NOx Technologies

Combustion Modifications

- Preliminary site investigations performed by Mitsubishi-Hitachi, SmartBurn and RV Industries
- SmartBurn concepts based on proprietary redistribution of primary and secondary air flows
- RV Industries based on a proprietary reconfiguration of the coal flow, as well as primary and secondary air flows (discussed on FuelTech slide)

Low NOx Technologies

FuelTech/RV Industries

- Consortium of FuelTech and RV Industries
- I-NOx System
- Have performed plant site visits and have suggested a combination of combustion modifications combined with either Selective Non-Catalytic Reduction (SNCR) or single layer SCR may achieve significant reductions
- Combustion modifications are considered confidential

Low NOx Technologies

AECOM Overview

- ROFA, RotaMix and LoTox
- ROFA - Rotating Overfire Air
- RotaMix - unit specific SNCR system with
- LoTox - Technology based on the injection of ozone upstream of the FGD system. Converts NO/NO₂ to soluble form of nitrous oxides (N₂O₅) that are removed in the FGD system.
- Requires cost effective source of ozone (partnership with Linde)
- Have performed site visits
- May be applicable to a pilot scale test

Low NOx Technologies

APCS - PeroxyChem

- Proprietary technology based on the injection of hydrogen peroxide with urea that allows for a broader operating temperature range and effectiveness for SNCR.
- Have performed site visits

Low NOx Technologies

Catalytic Filter Bags

- Received both public and one-on-one technical presentations from both Gore and FLSmidth on the application of catalyst impregnated fabric filter bags. These would replace existing fabric filters bags.
- Although initially promising, conclusions to date indicate that this technology would not be applicable given available temperatures (too low) and requirements for very low inlet SO₂ concentrations to prevent ABS formation on the filter bags

Low NOx Technologies

Next Steps

- Want to begin RFI/RFP process in early 2017. Most all technology suppliers require some form of Computational Fluid Dynamic (CFD) model of the boiler/back end. Need to initiate this effort as part of the first stage effort.
- Identify the key (non-Company) participants from the Clean Coal Research team for this RFI/RFP process

Low NOx Technologies - Budget

Year	Budget	Task
2017	\$100,000	Issue RFP for Advanced Low NOx Technologies and evaluate bids
2018	\$320,411	Select promising technology or technologies
2019	\$775,000	Install slipstream demonstration at Hunter or Huntington Plants
2020	\$220,411	Evaluate technology performance
Total	\$1,415,821	

Neural Nets – Sierra Club Questions

#1

- In PacifiCorp's June 2012 submittal to the Utah Division of Air Quality (UDAQ) of its analysis of best available retrofit technology (BART) for Huntington Unit 2, PacifiCorp considered a neural net operating system as part of its NOx BART analysis, but decided against it because "...the potential for significant and consistent NOx reduction is minimal." PacifiCorp's June 2012 BART Analysis for Huntington Unit 2 at 10.
- Given these statements made in 2012, what is different about the neural net controls proposed for Huntington 2 than what was considered in the 2012 BART analyses that would allow the controls to achieve the key performance indicator for success ("KPI") of NOx less than 0.15 lb/MMBtu?1

Neural Nets – Sierra Club Questions

#2

According to Rocky Mountain Power's STEP application at ¶38, the benefit of the neural net controls "will be targeted NOx emissions and *potentially* heat rate reductions" [emphasis added]. According to the information in Appendix F of Rocky Mountain Power's STEP Application, a key performance indicator for the project is a 0.75% reduction in net heat rate.² Is there a tradeoff between low NOx rates and a reduction in heat rate (i.e., that the neural net controls can achieve one but not both)? What other factors may be impacting the potential heat rate reductions achievable with the neural net controls?

Neural Nets – Sierra Club Questions

#3

According to Rocky Mountain Power's STEP Application, Taber International/Griffin Open Systems was selected as the provider of the artificial neural network software. Please identify the other vendors of neural net controls that were considered, and explain the basis for the selection of Taber International/Griffin? Also, please provide details on the experience of the University of Utah team in implementing neural net controls to minimize NOx emissions.

NOx Emission Controls – Neural Nets

#4

Is the neural network software compatible with the installation and operation of selective catalytic reduction (SCR) technology? If so, can the neural network software in conjunction with SCR and existing combustion controls reduce NOx emission rates below what is feasible for SCR and combustion controls alone?

#5

Will the neural net controls allow the Huntington Unit 2 to operate more hours per year at higher capacities due to the ability to ramp up more quickly? Does Rocky Mountain Power anticipate that the neural net controls will reduce forced outages, derates, and/or the length of planned outages? Is hourly generating capacity expected to increase with the neural net controls?

Neural Nets – Sierra Club Questions

#6

Does Rocky Mountain Power have any NOx emission rate guarantees with the vendor of the neural net controls? If so, what is the guarantee?

#7

What is Rocky Mountain Power's share, if any, of the project costs for the neural network controls each year over the next five years?

Neural Nets – Sierra Club Questions

#8

Please provide more details on the advanced combustion controls, the selective non-catalytic reductions and low cost catalysts, and the novel chemical conversion processes being investigated and the expected NOx emission rates? As part of this, please elaborate on the likelihood that these pollution control technologies can consistently achieve the NOx emission limits set by the EPA in its Regional Haze Federal Plan of 0.07 lb/MMBtu.

Neural Nets – Sierra Club Questions

#9

Paragraph 38 of the STEP Application describes a request for proposals “to achieve economic reductions in NOx emissions” in 2017. According to the project budget in Table 1, project expenditures are expected over four years, 2017-2020. What are the primary components of those expenditures? What is Rocky Mountain Power’s share, if any, of the project costs by year?

Neural Nets – Sierra Club Questions

#10

The direct testimony of Dr. Andrews states at p.3 that the project will involve “[i]mplementation of a utility scale demonstration of one or more alternative technologies that may result in decreases in NOx emissions without the use of Selective Catalytic Reduction (“SCR”),” and at p. 5 that it may “[f]acilitate future potential targeted NOx emissions reductions solutions that may be more economical than installing selective catalytic reduction system.” Please state whether the goal of this project component is to investigate potential cost-savings for Rocky Mountain Power.

Neural Nets – Sierra Club Questions

#11

Will Rocky Mountain Power delay engineering, procurement, and installation of SCRs for the Hunter and Huntington plants until it determines whether alternative NOx-reduction technology is available?

#12

Can Rocky Mountain Power meet its deadline for meeting NOx emissions reductions from Hunter Units 1 and 2 and Huntington Units 1 and 2 by 2021 as required by the Utah Regional Haze Plan if it delays engineering, procurement, and installation of SCRs?

Questions?