IPRO 303
2009

FAILURE PREDICTION MODELING OF POWER PLANT EMISSION CONTROL SYSTEMS

Students

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IPRO 303
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Sponsor: SmartSignal

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Addenda

The following are suggested resources and referenced to in this report that have been included. They are excellent sources to seek for additional information.

Babcock Power_SCR_basic.pdf
A presentation outlining the operation of Selective Catalytic Reduction in Babcock Power Plants

Crawford Tour_Environmental.ppt
Midwest Generation's presentation on the environmental control systems in their Crawford plant.

ESP_Failures_Table.pdf
A table from a ESP Operation and Maintenance class listing common failures and problems.

FGD Operation Manual.pdf
An EPA inspection manual for FGD systems.

Final_Presentation_Edited(4.30.09_9am).ppt
Our presentation to IPRO on our research and achievements.

Pleasant Prairie Power Plant.pdf
A pamphlets outlining the advancements of We Energies flagship power plant.

Practical Problems with Electrostatic Precipitators.pdf
A technical report from the Hammon Group on the common problems with the design and operation of ESPs.

EPA IL State Sulfur Regulations.pdf
A report from the EPA on Illinois's State regulations on Sulfur emissions.

Impact-of-FGD-Systems.pdf
A report from the Muscatine Board of Power and Water under the commission of the North American Electric Reliability Council on the reliability of FGD systems.

Mercury Emission Control In Coal-Fired Plants.pdf
A report detailing the use of Wet Scrubbers for Mercury control.

Self-Cleaning Filters Unclog Wet Scrubbers.pdf
An article on equipment used in the maintenance of Wet Scrubbers.

FGD_Operating_Experience_in Existing Plants.pdf
An article reviewing the use of Wet Scrubbers treating a variety of pollutants.

Scott Patulski Interview Notes.pdf
Notes from an interview with a contact from We Energies.

SCR Cost Data.pdf
A report detailing cost analysis of Selective Catalytic Reduction systems.

Control and Instrumentation of FGD.pdf
A technical report on the controls and instrumentation of FGD systems.

Table of Figures

Abstract

IPRO 303, Spring 2009, was tasked with gathering information about the emission control systems of coal fired power plants by their sponsor SmartSignal. SmartSignal is a company who uses software to do predictive maintenance on a number of industries, from airlines to power generators. SmartSignal wished to expand into the air emissions control systems of coal fired power plants. They asked the group to research the major subsystems of air emissions control systems and the laws that go along with each system. Having been assigned these tasks, the group broke up into different sub teams to accomplish the goals. The following paper outlines the groups response to SmartSignal's request, included is the process that was used to obtain results and the results obtained.

Background

Sponsor Information: SmartSignal is a corporation that provides applications to increase equipment performance by means of predictive analysis. SmartSignal's solution analyzes information gathered from equipment in power plants, monitors behavior of the plant as a whole, and identifies the risk of failures. SmartSignal's clients include a number of major power plants nationwide and worldwide. The company is located in Lisle, Illinois.

Current User Problems: Power Plants need to meet regulations assigned by local governments by reducing the expulsion of pollutants, and to detect failures of equipment that could potentially cost millions of dollars.

Sources Used: The team proceeded with their research through online databases and books on power plants and emission control. We used primary sources by visiting local power plants and interviewing staff.

Other Attempts to Solve the Problem: SmartSignal currently offers their services to the generation side of power plants. On the emission and the pollution control side of power generation most plants monitor the final emissions and perform manual inspections of the control equipment.

Ethical Issues: SmartSignal operates in a competitive market and any classified or sensitive information or documents obtained from the SmartSignal Company will be kept confidential and will not be disclosed to anyone outside the project team. Also SmartSignal specifically asked that their involvement as a sponsor NOT be disclosed outside the IIT community.

Business Cost: Failures on the emission control side of a power plant can have great societal and business costs. If pollutants are released above the prescribed regulations the health of nearby communities may be put in jeopardy. Crops and plant life may also suffer due to an excess of pollutants. Globally, the pollutants may spread further and may have global warming effects. The direct business costs to power plants can total in the millions. Pollution controls are often entire buildings themselves and costs millions of dollars to build. When they malfunction the repairs and fines for breaking regulations can cost the power plant as well. Additionally plants often will reduce production or shut down in order to fix failures. This can lead to excessive costs to supply the needed power to their customers or even lead to brown outs.

Implementation of the Solution: Our team researched these control systems for SmartSignal. From that point we made recommendations on how SmartSignal may implement their product and present their services to this sector of the market.

Similar Solutions Proposed: SmartSignal offers a unique and cutting-edge approach to predicting failures. Historically power plants monitor control systems in house and utilize manual inspections to predict failures in their control equipment. SmartSignal hopes to improve failure prediction on emission control systems.

Objectives

The main goal of IPRO 303 is to investigate how SmartSignal's modeling technology can provide value in detecting problems on environmental systems: The main objectives that SmartSignal would like for the team to investigate are:

- What are the regulatory drivers – changes in laws/regulation occurring at various points in time? Are the regulations fleet-wide or regionally specific? Can credits be traded? Etc.
- What types of systems are being deployed to remove what pollutants? Describe different sub-types and configurations within a type of system, and how common they are.
- How much instrumentation is available on these systems, and what signals are measured (temperature, pressure, chemistry analysis, etc.)? How much diversity is there in the levels of available instrumentation?
- What are the failure and performance degradation problems that occur? How common are they? What are the ramifications of these problems – outages, derates, having to burn more expensive fuel or turn up the "peaking" generation units that are more expensive to run, etc.?
- How can the available instrumentation be used to remotely monitor and detect developing problems?

SmartSignal would also like for us to compile a catalogue of information we find and the sources which are helpful for future research. We will submit a report that covers the overall findings of the research and provides any other supplemental information.

Methodology

The methodology of the project was changed slightly from the beginning of the project. The main reasons for these changes were to include more specific tasks, add additional tasks that the group completed over the semester, and allow for a realistic work time for each task. The Gantt Chart provided in section E below reflects these additions and modifications to the work breakdown structure. Of note is the difference between the actual completion dates of tasks, and the original proposed completion dates. At the beginning of the semester, it was the aim of the group to have all tasks completed two weeks before the final due date so as to avoid rushing to complete tasks at the last possible time. A breakdown of the stages of the group's research is as follows:

A. Defining the problems: SmartSignal, our sponsor, provides software to aid in predicting equipment failure on the generation side of power plants and wished to break into the emissions control side. It was the wish of SmartSignal for the group to investigate the opportunities for SmartSignal modeling technology to provide value in detecting problems on environmental systems. They provided us with five specific topics to research:

- Emissions regulations for coal fired power plants
- Different emissions control systems
- Instrumentation available for the control systems and what it measures
- Common failures and degradations of the control systems
- Relate indications from instrumentation to specific failures of the control systems

B. Gathering research: SmartSignal wanted emphasis to be placed on the last three tasks, but first a base knowledge of each system had to be acquired, thus the first stage of research involved finding:

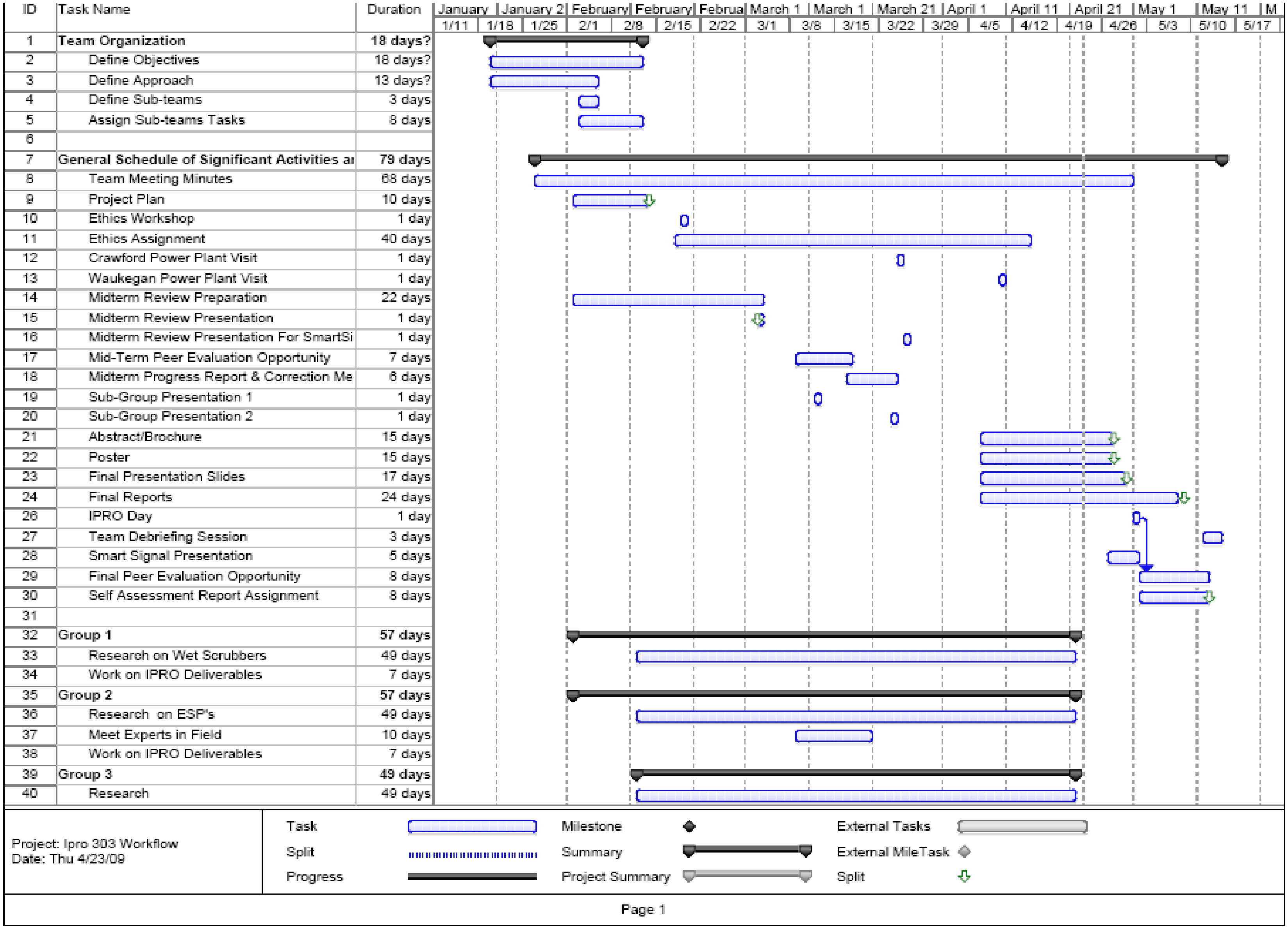
- Which pollutant each control system regulates
- The regulation processes of each control system
- Different configurations of the emissions control systems

Once the group gained a basic knowledge of the systems, the final three tasks could become the focus of the research.

C. Initial data compilation and feedback: The group's research was compiled in a report which served as both the midterm report and a team progress report. The sponsor was contacted to provide feedback as to the direction the project had been going and where it was headed.

D. IPRO Day: As the project did not produce a working prototype, the results of the semester were exhibited using tables and pictures. The project goals and conclusions were included in the final presentations and exhibit.

E. Work Breakdown Structure: The Breakdown Structure of the work that was done by the group is given in the Gantt Chart below:



ID	Task Name	Duration
1	Team Organization	18 days?
2	Define Objectives	18 days?
3	Define Approach	13 days?
4	Define Sub-teams	3 days
5	Assign Sub-teams Tasks	8 days
6		
7	General Schedule of Significant Activities a	79 days
8	Team Meeting Minutes	68 days
9	Project Plan	10 days
10	Ethics Workshop	1 day
11	Ethics Assignment	40 days
12	Crawford Power Plant Visit	1 day
13	Waukegan Power Plant Visit	1 day
14	Midterm Review Preparation	22 days
15	Midterm Review Presentation	1 day
16	Midterm Review Presentation For SmartSi	1 day
17	Mid-Term Peer Evaluation Opportunity	7 days
18	Midterm Progress Report & Correction Me	6 days
19	Sub-Group Presentation 1	1 day
20	Sub-Group Presentation 2	1 day
21	Abstract/Brochure	15 days
22	Poster	15 days
23	Final Presentation Slides	17 days
24	Final Reports	24 days
26	IPRO Day	1 day
27	Team Debriefing Session	3 days
28	Smart Signal Presentation	5 days
29	Final Peer Evaluation Opportunity	8 days
30	Self Assessment Report Assignment	8 days
31		
32	Group 1	57 days
33	Research on Wet Scrubbers	49 days
34	Work on IPRO Deliverables	7 days
35	Group 2	57 days
36	Research on ESP's	49 days
37	Meet Experts in Field	10 days
38	Work on IPRO Deliverables	7 days
39	Group 3	49 days
40	Research	49 days

Project: Ipro 303 Workflow
Date: Thu 4/23/09

Task
Split
Progress
Milestone ◆
Summary
Project Summary
External Tasks
External MileTask ◆
Split ⇩

Page 1

Figure 1: Gantt Chart

Team Structure and Assignments

As a team we addressed the issues of team structure and task assignment through a series of steps. At first we operated with no formal leader or team structure and relied on a group consensus and then by a vote as a last resort. Each team member put forth a data sheet detailing their expertise and skills. We started assigning tasks through volunteering and consensus on which member was the most qualified to complete the task. Insiyah Aratsu and Sean Irish, our two Architects, volunteered their design experience to develop a team logo. Lavesh Mohinani and Jay Patel offered to provide a Gantt Chart for the group. Satyam Kaneria and Jay Patel took charge of managing our iGroups files. Zachary Capps and John Bouikidis began attempting to contact Power Plants to set up a tour. The rest of the team began to focus on preliminary research and preparing the Project Plan. Next, we divided ourselves into three subgroups to tackle research. Each subgroup was focused on a specific topic our sponsor had asked us to investigate. These subgroups were Electrostatic Precipitators/Baghouses, Selective Catalytic Reducers and Wet Scrubbers. This method provided a high quality of work, but low efficiency. By midterm we had decided that a formal group leader should be chosen to direct the overall organization and provide a vision for our final result. This decision would also increase the efficiency of our progress. Brett McQuillan volunteered to be the overall leader and the decision was agreed upon by consensus. Subtasks were then defined in greater detail and each subgroup chose a leader as well. A second third phase of our organization was developed and is detailed in the table below. After a brief meeting with our sponsor, we redoubled our research efforts to meet their needs.

	Team Structure Chart	
	Phase I: Research	
Wet Scrubbers	*ESPs/Baghouses*	*SCRs*
Insiyah Arastu	*Zachary Capps	Dave Belanger
John Bouikidis	Satyam Kaneria	Cari Hesser
*Brett McQuillan	Lavesh Mohinani	*Sean Irish
Jay Patel		
	Phase II: Extended Research	
Power Plant Contact	*Regulations*	*Formatting*
Insiyah Arastu	Cari Hesser	Insiyah Arastu
Dave Belanger	Satyam Kaneria	Sean Irish
John Bouikidis	*Brett McQuillan	*Lavesh Mohinani
Zachary Capps		Jay Patel
	Phase III: Presentation	
Poster/Brochure	*Final Report*	*Final Presentation*
Insiyah Arastu	Zachary Capps	Insiyah Arastu
*Sean Irish	Cari Hesser	Dave Belanger
Jay Patel	Satyam Kaneria	Sean Irish
	*Brett McQuillan	*Lavesh Mohinani
	John Bouikidis	

Figure 2: Team Structure Chart

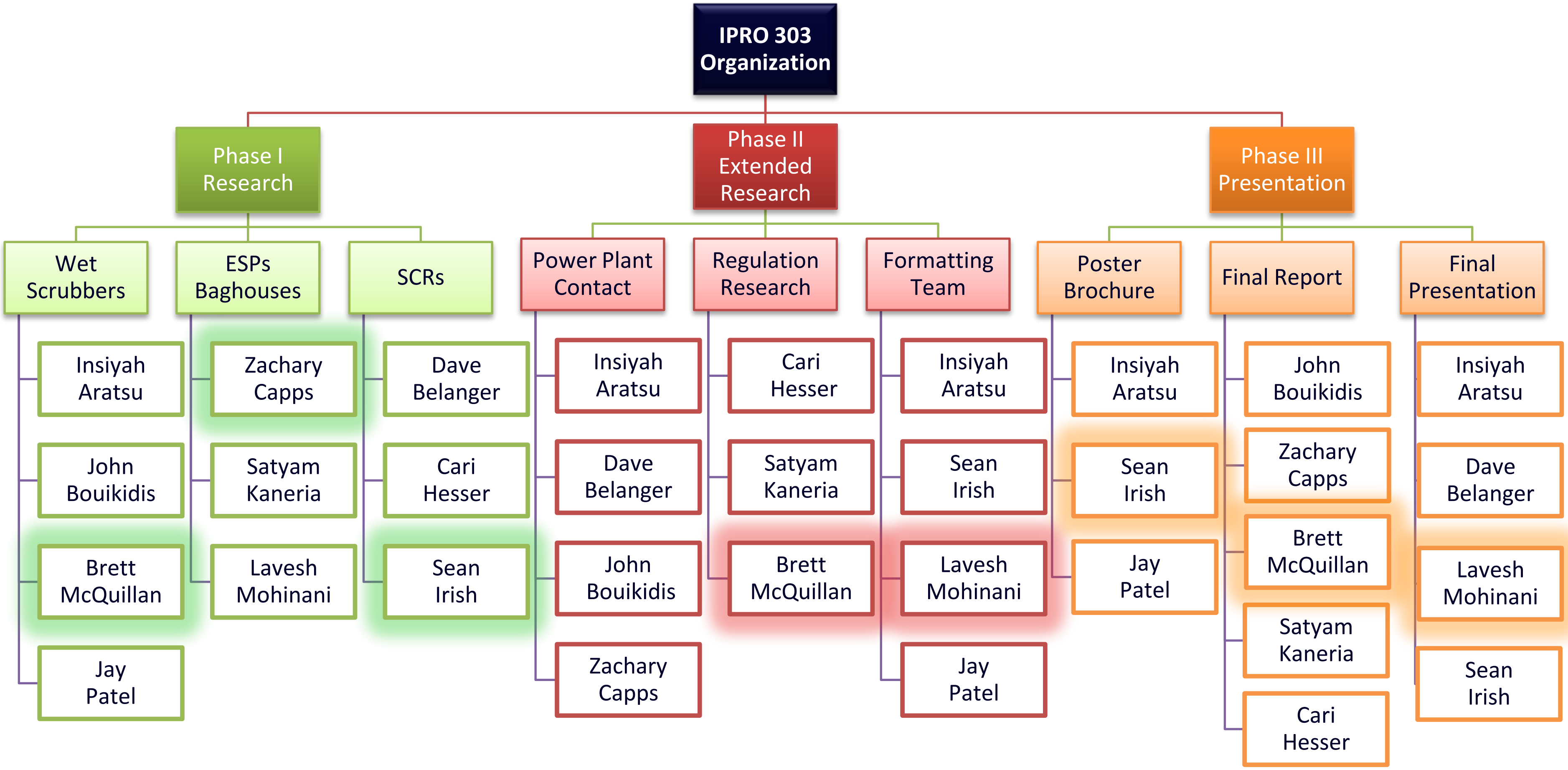


Figure 3: Team Structure Flow Diagram

Budget

	Travel		Miscellaneous		IPRO Day	
Estimated Expenses:	$250.00	Location Driven	$200.00	Reason	$100.00	Reason
Actual Expenses:	$31.90	Ed's travel to MG Crawford	$27.98	Einstein Bagels for 2 IPRO Meetings		
	$34.52	Ed's travel to MG Waukegan	$13.12	Chips and Pop		
	$8.80	Insiyah's travel to MG Crawford	$55.86	Jimmy Johns		
	$63.18	John's travel to MG Waukegan				
Sub-Totals:	$138.40		$82.97		$0.00	
Total:	$221.37					

Figure 4: Budget

*MG=Midwest Generation

Ethics

In order to tackle the ethics issues we encountered, the group decided to split into 3 different groups and was assigned to read an article on an ethical perspective. The perspectives were given to us by our professor.

Those articles are hereby listed as: Seven Layers of Integrity by June Ferrill, Ethics, It's Good Business, and Professional Engineering Code of Ethics (ASME Code)

The members of the groups are shown in the table below.

Professional Engineering Code of Ethics	**Seven Layers of Integrity**	**Ethics, It's Good Business**
Insiyah Arastu	Cari Hesser	Zachary Capps
David Belanger	Brett McQuillan	Sean Irish
John Bouikidis	Lavesh Mohinani	Jay Patel
Satyam Kaneria		

Figure 5: Ethics Perspectives

The first issue we were concerned with was not disclosing SmartSignal as our sponsor. While this IPRO team did not sign a contract or make a formal agreement with SmartSignal to not disclose their name, we were respectful of their request. Any question that was asked of an outside source was carefully formulated so as not to reveal any sort of involvement with another company. When asked about why we

were interested in learning about power plant emission control systems, our group always responded that this was a school project. While it may not have been entirely true, we still had an obligation to not disclose SmartSignal's name. No outside contacts directly asked us if we had a sponsor.

The second issue was concerned with unequal contribution from individual team members. While our team did stumble upon unequal contribution between members, we were able to take steps to iron out the wrinkles and assign other tasks to members when it became necessary. Our group looked down upon unequal contribution between members. Each member was assigned a task to do and was responsible for the completion of their assigned tasks. The groups came to the consensus that: Members needed to contribute equal work to maintain a good reputation within the group, team members should be honest with the amount of work they do, and members should always give credit where credit is due.

The third issue dealt with how team members may be impacted by diversity within the team. This IPRO team did not encounter any such an issues, as IIT is an incredibly diverse school, and its students deal with diversity every day.

It is important to follow the code of ethic guides given by The Seven Layers of Integrity, Ethics, It’s Good Business, and the ASME Code of Ethics. These guides provide a basic structure for creating a well functioning team. They show the importance of honesty, loyalty, hard work, and equality within a group.

Results

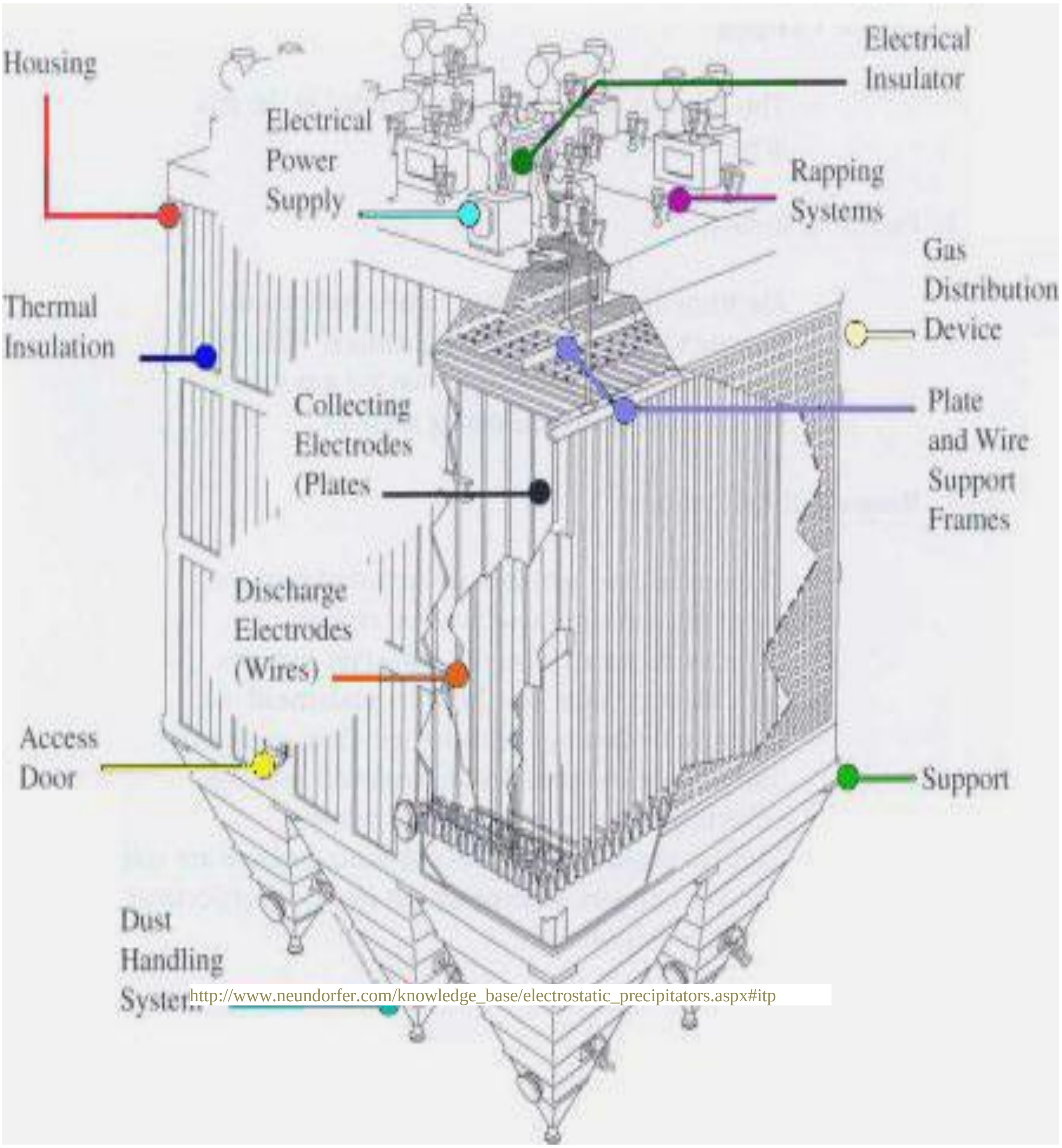
Electrostatic Precipitators (ESPs)

The Electrostatic Precipitator team had primary objective of learning how the Electrostatic Precipitators (ESPs) and Fabric collectors (Bag Houses) work and then go onto the details of their failure conditions and the instrumentation available on them to detect and prevent it, which was the main aim from the sponsor SmartSignal.

Electrostatic Precipitators, also commercially known as ESPs or Precipitators are industrial emission control units. It is designed to trap dust particles from any particulate laden gas by electrically charging this gas and passing this gas through charged metal plates that will collect the particles to its surface. Precipitators are used in many industries such as Power/Electric, Chemical, Metals, and Paper.

Precipitators function by electrostatically charging the dust particles coming out from any industrial process and then collecting these on metal plates with the help of high electric field created between these plates so as to deposit particles on them. The figure 6 shows a commercial precipitator and there are six processes that take place in a precipitator.

- Ionization – This is the initial process of charging the dust particles from any process
- Migration – Transporting the particles to the collecting surface
- Collection – Precipitating the particles on to that surface
- Charge Dissipation – Neutralizing the charged particles to facilitate its collection on the surface
- Particle Dislodging - Removing the particles from the collecting surface to hopper (hopper is a collecting area for particles).
- Particle Removing – Putting the particles to its disposal area via a conveyor.



http://www.neundorfer.com/knowledge_base/electrostatic_precipitators.aspx#itp

Figure 6: Electrostatic Precipitator

After spending some time learning about these systems, we then started collecting information that lead to their failure and the type of the instrumentation or instrumentation systems available to predict those conditions either in real time or in advance.

The table below gives the detailed description of the ESP failures and associated corrective measures.

Summary of Problems Associated with Electrostatic Precipitators

Malfunction	Cause	Effect on system efficiency	Corrective action	Preventive Measures
1. Poor electrode alignment	1. Poor design 2. Ash buildup on frame hoppers 3. Poor gas flow	Can drastically affect performance and lower efficiency	Realign electrodes Correct gas flow	Check hoppers frequently for proper Operation
2. Broken electrodes	1. Wire not rapped clean, causes an arc which embroglios and burns through the wire 2. Clinkered wire.	Reduction in efficiency due to reduced power input, bus section unavailability	Replace electrode	Boiler problems; check space between recording steam and air flow pens, pressure gauges, fouled screen tubes
3. Distorted or skewed electrode plates	1. Ash buildup in hoppers 2. Gas flow irregularities 3. High temperatures	Reduced efficiency	Repair or replace plates Correct gas flow	Check hoppers frequently for proper operation; check electrode plates during outages
4. Vibrating or swinging electrodes	1. Uneven gas flow 2. Broken electrodes	Decrease in efficiency due to reduced power input	Repair electrode	Check electrodes frequently for wear
5. Inadequate level of power input (voltage too low)	1. High dust resistivity 2. Excessive ash on electrodes 3. Unusually fine particle size 4. Inadequate power supply 5 Inadequate sectionalization. 6. Improper rectifier	Reduction in efficiency	Clean electrodes; gas conditioning or alterations in temperature to reduce resistivity; increase sectionalization	Check range of voltages frequently to make sure they are correct; check insitu resistivity measurements

	and control operation 7. Misalignment of electrodes			
6. Back corona	1. Ash accumulated on electrodes causes excessive sparking requiring reduction in voltage charge	Reduction in efficiency	Same as above	Same as above
7. Broken or cracked insulator or flower pot bushing leakage	1. Ash buildup during operation causes leakage to ground 2. Moisture gathered during shutdown or low-load operation	Reduction in efficiency	Clean or replace insulators and bushings	Check frequently; clean and dry as needed; check for adequate pressurization of top housing
8. Air leakage through hoppers	1. From dust conveyor	Lower efficiency; dust reentrained through electrostatic precipitator	Seal Leaks	Identify early by increase in ash concentration at bottom of exit to ESP.
9. Air in Leakage through ESP Shell	1. Flange expansion	Same as above; also causes intense sparking	Seal leaks	Check for large flue gas temperature drop across the ESP
10. Gas bypass around ESP • **Dead passage above plates** • **Around high tension frame**	1. Poor design; improper isolation of active portion of ESP	Only few percent drop in efficiency unless sever	Baffling to direct gas into active ESP Section	Identify early by measurement of gas flow in suspected areas

Figure 7: ESP Failure Chart

The failure conditions of the Baghouses included its gradual deterioration and its susceptibility to fire. A baghouse is composed of fiber and is exposed to high temperature flue gas from the flue gas. Additionally, cinders and embers from the boiler can cause fires within the Bag House.

After finding the failures of the different systems, we then looked into the instrumentation that was available to monitor these systems in a real time manner. During our term, we had made a couple of power plant visits which helped us in gathering information about instrumentation of the systems.

The electrostatic precipitators at Crawford Plant were monitored using Forry ESP products. The program is remotely accessible to all computers on the network. The program allows user to monitor

- sparks/minute
- arc/minute
- primary/secondary voltage

The primary indicators on the machine give real-time values for

- primary and secondary voltage
- current sparks and
- arcs per minute
- kilowatts
- firing angles
- actual conditions versus programmed
- current parameters versus transformer ratings

Forry Products include various alarms for when the Electrostatic Precipitator does not work as it is supposed to. Some of the alarms include

- back Corona alarm,
- transformer temperature input alarm and
- Selective Catalytic Reducers temperature input alarm

It also allows users to define violations on the system. These systems are also capable of graphically displaying VI curves:

- 5 minutes to 24 hours kW trends
- spark simulation

The rappers can also be controlled using Forry Rapper Control. The instrumentation on these systems includes

- on-time/repeat time
- frequency
- rapper direction and
- rest time

Baghouses

Baghouses are used to remove fly ash from the flue gas stream. Baghouses are primarily used in Europe because the power plants in Europe have a huge pressure differential which is required to pass the gas through the filters. In the states, they are only found at 10% of power plants. Baghouses have a series of filters that filter the air. The three most common types of baghouses derive their name from how they handle dust removal.

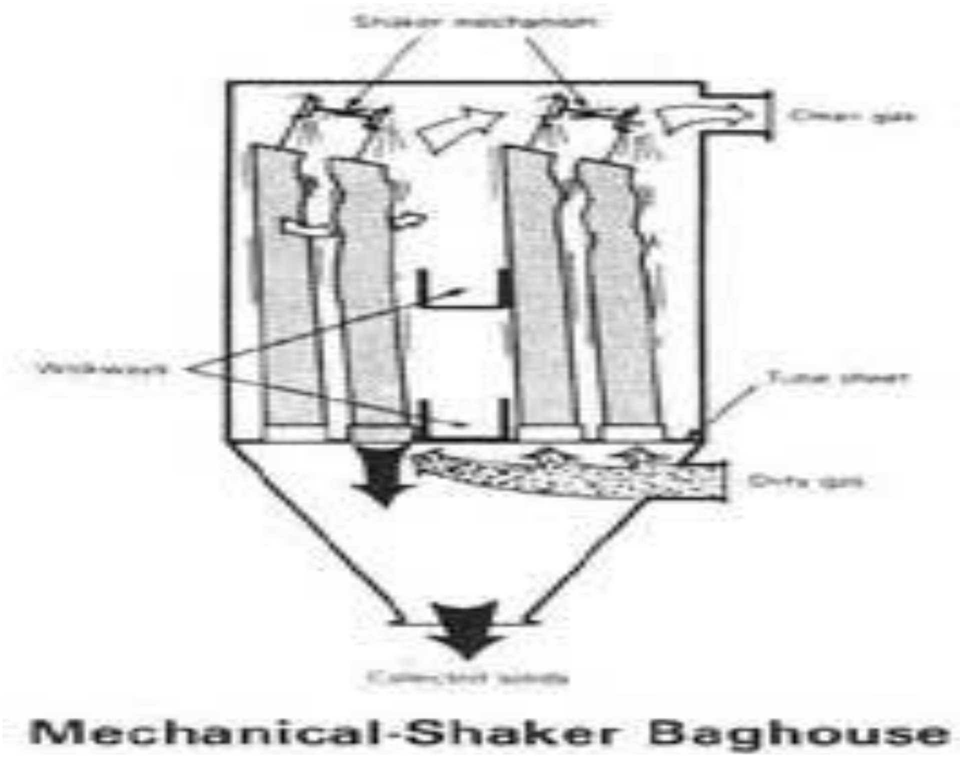


Figure 8: Baghouse Diagram

The first type of baghouse, shown on the right in Figure 8, is the mechanical shaker. In the mechanical shaker, a mechanical motor is used to shake the sheets of fabric during dust removal. The air to cloth ratio, which is the volumetric flow rate of the air divided by the cloth area, is between 2-4 to 1. This baghouse has several different compartments which allows for it to divert air from the compartment being cleaned to one that is not being cleaned

The instrumentation available for baghouses includes pressure gauges before and after the baghouse to look at the pressure differential across the bag. There is also an instrument called "The Broken Bag Detector" that can detect dust in the air. This instrument uses the triboelectric effect to detect dust particles: the triboelectric effect is the surface charge interaction that occurs when two different materials go past each other, for this case the two different materials are a probe that can detect voltage and the dust particles themselves. The last bit of instrumentation that was found with baghouses looks at the opacity of the exiting gas.

Symptom	Cause	Remedy
High Baghouse pressure drop, LOW Cubic feet per minute	Bag Cleaning Mechanism not adjusting properly	Increase cleaning frequency. Clean longer duration
	Not Capable of Removing dust from bags	Send sample of dust to manufacturer. Send bag to lab for analysis for blinding. Dry clean or replace bags
	Excessive Reentrainment of dust	Continuously empty hopper. Clean row of bags randomly instead of sequentially
	Incorrect pressure reading	Clean out pressure taps Check hoses for leaks. Check diaphragm in gauge
Low Baghouse pressure drop, High cubic feet per minute	Pressures will be less with high temperature gases or at high altitudes	Reduce fan speed
	Filter bag ruptured	Check for visible emission from stock
	Fan speed too high	Check drives
	Ambient air infiltrating system	Check all doors and hatches. Check system for leakage.
Low Baghouse pressure drop, Low cubic feet per minute	Induced draft fan failure	Check fan rotation, drives and speed
	Restrictions in duct before or after	Check all dampers. Check fan damper. Check for dust plugging ductwork. Review duct design, (may be more restrictive flow than expected). Increase Fan speed.

Figure 9: Baghouse Failure Chart

As part of the objectives the team was also responsible for stating the laws that govern allowed emission levels.

Mercury and Mercury Regulations

Mercury is bonded to the carbon that is injected during carbon injection of the flue gas stream. This newly formed compound migrates down to the electrostatic precipitators or baghouse and gets caught: it gets caught because the compound is fly ash and ESPs and Baghouses remove fly ash into the atmosphere.

Federal Laws

The Clean Air Mercury Rule (March 15, 2005) was a law by the EPA which mandated mercury emission control on coal fire power plants. The EPA stated that power plants must use a MACT standard (maximum achievable control technologies) which states that power plants have to use the maximum achievable control technologies and that they are given a time table to implement these technologies . This rule also stated that a cap and trade program on the amount of mercury content was to be setup.

Fourteen states, various environmental groups, and several Native American tribes challenged the CAMR in 2005. They stated that cap and trade programs would cause hot spots of mercury also they argued that CAMR went against the Clean Air Act by illegally removing coal and oil fire power plants from the list of regulated emitters of mercury.

The states, environmental groups, and Native American Tribes won their lawsuit. The lawsuit was appealed all the way up to the Supreme Court with help of the Bush Administration. The Obama administration requested that the Bush administration's request for appeal be dropped and the Supreme Court granted that request. The Clean Air Mercury Act is no longer effective.

State Laws

Connecticut became the first state to regulate mercury emissions from coal fire power plants by passing a law in 2003 that said that coal fire power plants must reduce mercury emissions by 90% by July 1, 2008.

New Jersey passed a law on January 5, 2004 that coal fire power plants must also reduce mercury emissions by 90% and that they have until 2007 to do it.

Massachusetts' Department of Environmental Protection in June 2004 put out a regulation that states that four of the states large coal fire power plants must reduce mercury emissions by 85% by January 1, 2008 and then by 95% by October 1, 2012.

New Hampshire's State Legislature in 2002 told New Hampshire's Department on Environmental Services to come up with rules establishing a cap on mercury emissions.

Wisconsin's Department of Natural Resources came up with 90% reductions in mercury emissions of coal fire power plants by January 1, 2015.

Colorado, Hawaii, Iowa, New York, Virginia, and Washington all have bills currently circulating around their state legislators that would limit mercury emissions.

The Effects of Mercury:

Mercury emissions from power plants are in the form of gas and average 48 tons. This gas cycles through the atmosphere and winds up in soil and water. The fish in the water absorb the mercury which can make the fish unsafe to eat: to quantify this, only 1/70th a teaspoon of mercury is needed to cause the fish in a 25 acre lake unsafe to eat. Mercury can cause brain damage to fetuses and developing minds.

Selective Catalytic Reducers (SCRs)

The Selective Catalytic Reducer team had the primary objective of learning how the SCRs work and then go onto the details of their failure conditions and the instrumentation available on them to detect and prevent it.

The purpose of a selective catalytic reduction system is the reduction of Nitrogen Oxide (NOx) gasses from the flue gas produced by the boilers in coal fired power plants**.** The reduction process consists of the following steps: Flue gas from the boiler is mixed with a solution of aqueous, anhydrous, or urea based ammonia, and fed through a high temperature chamber containing a metal catalyst. The mixture of ammonia and flue gas comes in contact with the catalyst surface, and a chemical reaction takes place that converts the NOx and NH_3 to nitrogen gas and water vapor. The main chemical reactions occur between the NOx gasses and ammonia:

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$
$$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$$

Other chemical reactions involving the creation of sulfur oxides, ammonium sulfate, and ammonium bisulfate occur during the process as well:

$$SO2 + 1/2\ O2 \rightarrow SO3$$
$$2NH3 + SO3 + H2\ O \rightarrow (NH4)2SO4$$
$$NH3 + SO3 + H2O \rightarrow NH4HSO4$$

Typical SCR components consist of ammonia storage tank(s), pump, mixer/injection grid, and the catalyst bed, all of which can be seen in the figure below:

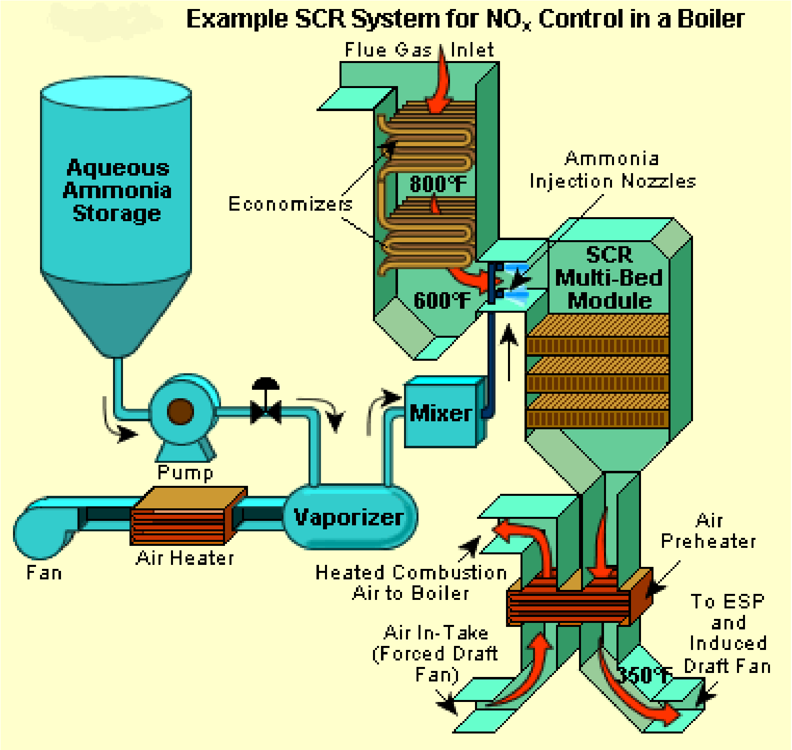


Figure 10: Selective Catalytic Reduction Schematic

Depending on the design of the power plant, one of three main configurations can be used:

- Hot Side, High Dust: upstream of the air preheater (APH) and electrostatic precipitator (ESP)
- Hot Side, Low Dust: upstream of the APH and downstream of the ESP
- Cold Side, Low Dust: downstream of the APH and ESP

The hot side, high dust setup is the most common configuration throughout power plants in the United States.

The two most important aspects of proper SCR functionality are operating temperature, and ammonia slip. The paragraphs below give details as to why this is so.

Operating Temperature: The cost of the catalyst metals alone is 15-20% of the capital cost of an SCR unit (between $9000-13000 per square meter); thus it is very important to operate at as high a temperature as possible because this will maximize space velocity and thus minimize catalyst volume needed. It is also necessary to minimize the rate of oxidation of SO2 to SO3, which is more temperature sensitive than the SCR reaction. The optimum operating temperature for the selective catalytic reduction process using the most common catalysts, titanium, tungsten and vanadium oxide, is about 650-750°F.

Ammonia Slip: Unreacted ammonia in the flue gas downstream of the SCR reactor is referred to as ammonia slip. It is paramount that ammonia slip not exceed 5 ppm, preferably 2-3 ppm, so as to minimize the formation of ammonium sulfate and ammonium bisulfate, which can cause plugging and corrosion in the equipment. Additionally, it is important to monitor ammonia slip because of its harmful effects on the environment and human health when too much slips through the system unreacted. Ammonia slip is a greater problem with high-sulfur coals, caused by higher SO3 levels resulting from both higher initial SO3 levels due to fuel sulfur content and oxidation of SO2 in the SCR reactor.

The table below gives a detailed description of the most common failures associated with Selective Catalytic Reduction Systems, along with any corrective and preventative measures that can be taken.

Summary of Problems Associated with Selective Catalytic Reducers

Malfunction	Cause	Effect on System	Corrective Action	Preventative Measures
1.Catalyst Deactivation	1. Catalyst poisoning ▪Deactivation of the Catalyst by chemical attack	1. Reduces Efficiency of NOx Removal	1. Replace Catalyst	Soot Blowers (to accommodate for blockage and plugging)
		2. Ammonia Slip	2. Clean Catalyst	
	2. Catalyst Masking ▪Microscopic blockage of the catalyst surface by dense second phase coating	1. Reduces Efficiency of NOx Removal	1. Replace Catalyst	Screens to block out fly ash particulates
		2. Ammonia Slip	2. Clean Catalyst	

	3. Catalyst Plugging ▪Macroscopic blockage of the catalyst system pore system by small flash ash particles	1. Reduces Efficiency of NOx Removal	1. Replace Catalyst	Sonic Horns
		2. Ammonia Slip	2. Clean Catalyst	
2. Catalyst Deterioration	Use across life span causes the catalyst to deteriorate	1. Reduces Efficiency of NOx Removal	Replace Catalyst every 3-7 years	None. Deterioration is an unavoidable phenomenon that happens over the SCR's life span.
		2. Ammonia Slip		
3. Ammonia Slip	1. Unreacted ammonia exiting SCR reactor	No effect on system, effects level compliance with regulations for NOx and ammonia emissions	1. Ensure Mixer is working properly 2. Adjust ammonia supply	1. Some slip is expected. Monitor gas sensors to maintain an acceptable range of slip.
	2. Un-even distribution of ammonia and flue gas across catalyst surface	No effect on system, effects level compliance with regulations for NOx and ammonia emissions	Prevent clogging of the ammonia injection grid	1. Correct design of SCR system 2. Monitor gas sensors for proper ammonia and flue gas mix ratios
4. Broken Pump	1. Broken Housing or Shafts From: ▪Excessive vibration, causing: i. Bent, cracked or broken fan ii. Fan not squarely mounted on shaft iii. Cracked or bent pulleys due to improper handling or installation ▪Belts to tight, causing: i. Excessive loading ii. Bending force on the shaft causing a deflection from the center of rotation	Improper distribution of flue gas and ammonia	Replace Pump	1. Do not overload pump 2. Inspect pump during installation

Figure 11: SCR Failure Chart

Noticeably absent from the above table is any instrumentation. SCR systems are fairly simple in nature, thus there is not a lot of instrumentation necessary to monitor SCR performance. The two most important forms of instrumentation are temperature gauges, and gas sensors. The temperature gauge will tell the operator if the SCR is operating within its optimal temperature range. Reasons as to why this is important are detailed later in this section. The gas sensors can measure the amount of a particular chemical present in the gas flow, so they are very useful in monitoring the amounts of ammonia and NOx gases in the air both before and after the SCR system. Reasons for monitoring ammonia slip, as with temperature, are

detailed later in this section. Monitoring NOx both before and after the SCR system gives a good indication of both the percent NOx reduction the system is achieving, and if output NOx complies with regulations.

More instrumentation may be available/used on SCRs in service, however, relatively few power plants utilize SCR technology at this time, and thus it is possible that insufficient data on instrumentation was collected.

Advantages:

- NOx reduction of up to 92%
- Fairly simple system to monitor

Disadvantages:

- Incredibly expensive to operate and maintain
- Ammonia used for reduction reaction is dangerous to transport and deal with
- Process can create destructive amounts of ammonium sulfate and ammonium bisulfate if not carefully monitored

NOx Regulations for Solid Fuel Type Boilers in the USA:

Status	Wattage Range (MW)	2008 Regulations (mg/m^3)	2016 Regulations (mg/m^3)
Existing Units	50-500	600	300
Existing Units	>500	500	200
New Units	50-100	N/A	400
New Units	100-300	N/A	200
New Units, biomass fueled	100-300	N/A	300
New Units	>300	N/A	200

Figure 12: NOx Regulation Chart

Overall: Much of the information on SCRs beyond that of basic operation and components was obtained late into the semester when Babcock Power, an SCR manufacturer, finally responded to our request for information. We feel that our research on NOx regulations, SCR functionality, and common SCR malfunctions and failures was comprehensive; however, our research on failure indicators could be much more in depth. If we had had more time, potentially our contact at Babcock Power could have provided us with that sort of information, so it would be wise for future IPROs in this area to make use of this contact.

Wet Scrubbers (FGD)

Purpose

- Flue Gas Desulfurization
- Removes Fly Ash particulate

Common Design Types depending on use

- Fly Ash: Venturi, Packed Bed, Impingement Plate
- FGD: Spray Tower

Advantages

- Small space requirement
- Treats particles in gas
- Treats high temperature and high pressure

Disadvantages

- Corrosion problems
- High power usage
- Water pollution problem

Although a variety of Wet Scrubbers exist, they all share a few common characteristics. They "scrub" undesirable pollutants out of gas streams by introducing a particular liquid depending on the pollutant. Most Wet Scrubbers are used in coal-fired power plants to target Sulfur Oxide gases through a method called Flue Gas Desulfurization (FGD). These types of scrubbers operate through a chemical reaction caused by interaction between the scrubbing liquid and the gas. In coal flue gas, a limestone slurry is typically used to react with the sulfur dioxide in order to form a synthetic gypsum precipitate. The gypsum particulate can be sold and transformed into the common building material gypsum board. The chemical reaction is as follows:

$$SO_2 + CaCO_3 + 1/2O_2 + 2H_2O = CaSO_4.2H_2O + CO_2$$

Alternate Wet Scrubber designs can also be used to treat and remove fly ash and other particulates from the flue gas. This type of scrubber is designed to have a shorter retention time for the gas and narrow chambers to increase the contact area between the scrubbing liquid and the particulates. Properly designed Wet Scrubbers operate in efficiencies over 99% in both Flue Gas Desulfurization and Fly Ash removal. They operate at pressure drops between 6 and 70 inches of water but most commonly around 10 inches of water.

The regulations that drive the design of Wet Scrubbers are primarily set by the EPA. Regulations were set in response to public outcry regarding acid rain. Sulfur Oxides have been linked to acid rain, the poisoning of crops and vegetation as well as increased cancer rates in humans and in animals. Some states also set stricter regulations of Sulfur Oxide pollution. Currently the regulation states that power plants do not exceed 0.03 parts per million SOx over a calendar year. An additional regulation of no more than 0.14 ppm may be emitted over the course of twenty four hours more than once over the course of a calendar year. The federal regulations are growing stricter and will require the majority and then eventually all coal-fired power plants to install FGD systems to meet tighter regulations.

Several types of Wet Scrubbers exist. The most common Wet Scrubber in coal-fired power plants is the Spray Tower. This design contains a series of nozzle racks stacked vertically on top of each other. The dirty flue gas enters from the bottom of the tower and is allowed to react as the gas rises and interact with the liquid spray. The gas exits through the top of the tower after passing through a mist eliminator. The mist eliminator catches liquid droplets that might escapes into the stack. This mist eliminator can be a major maintenance concern due to plugging or damage from the hot corrosive flue gas.

Other common Wet Scrubbers used for the treatment of fly ash are Venturi, Impingement Plate and Packed Bed Scrubbers. All of these scrubbers pass the gas through a small area to allow the maximum contact with the scrubbing liquid, often spray into this area by nozzles.

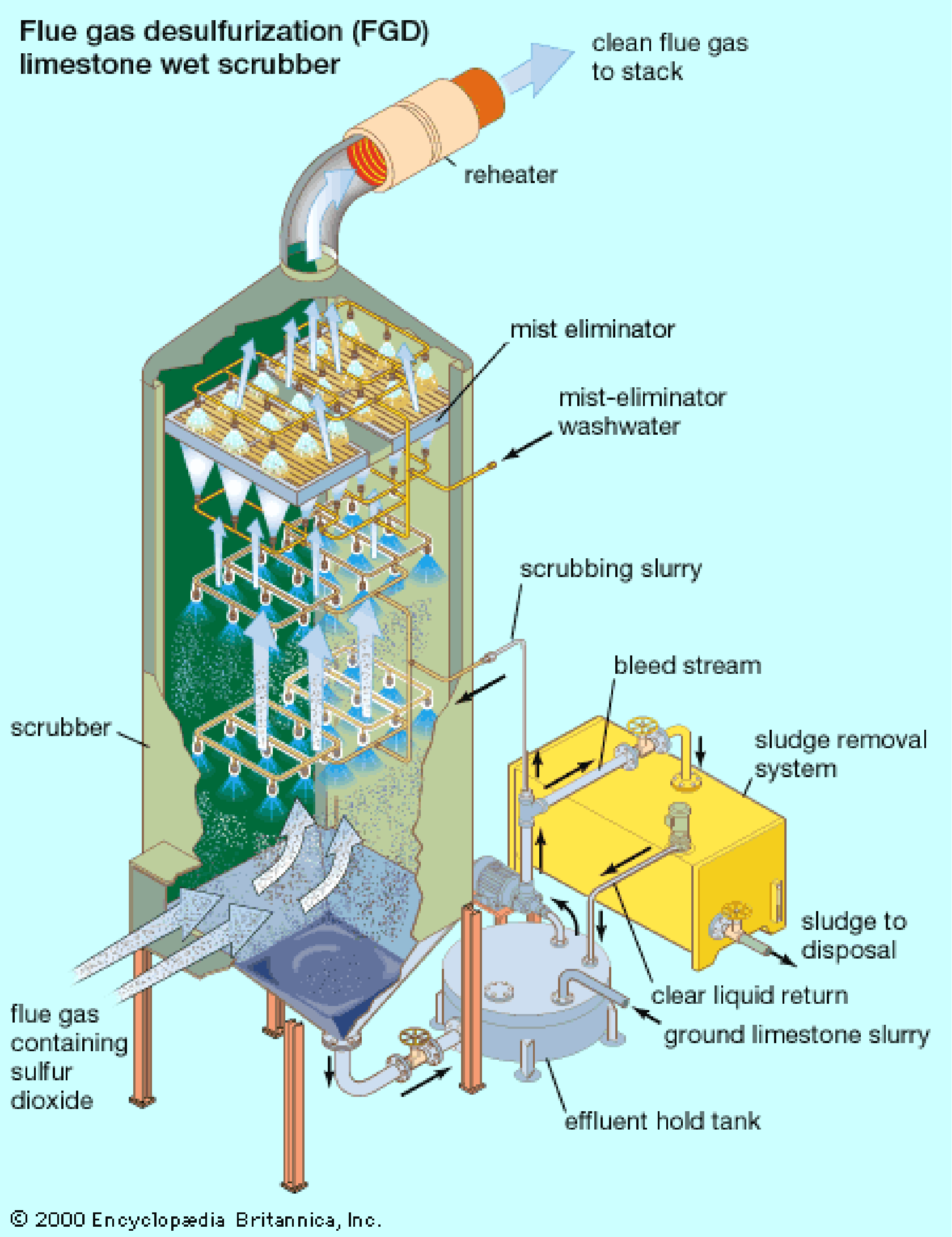


Figure 13: Wet Scrubber, FGD Spray Tower

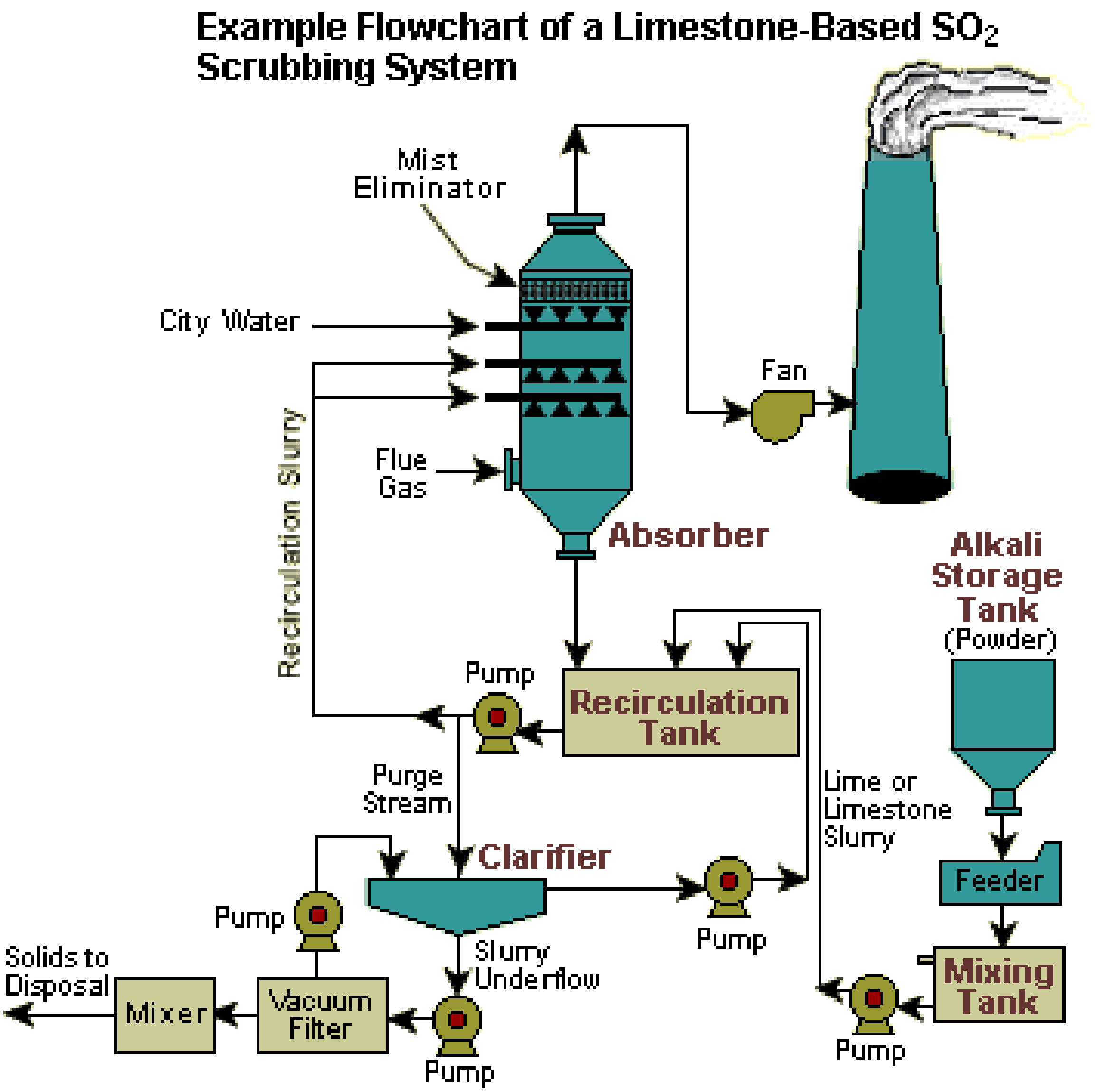


Figure 14: Wet Scrubber FGD Schematic

Wet Scrubbers use a variety of instrumentation and are widely accepted to be the most complex of the major air pollution control systems. This intricately is due to the liquid component of the system. The scrubbing slurry must be monitored as well as the flue gas. The slurry is monitored using pH, pressure, temperature and humidity sensors. The walls and containment is monitored using acoustic and vibration sensors to locate corrosion. Common issues that arise from the limestone slurry are pH imbalance, corrosion and plugging in the delivery (nozzle) systems. The flue gas is monitored using pressure, temperature and humidity sensors. The flue gas instrumentation can detect potential problems with the mist eliminator, fans, and containment. The major downside of Wet Scrubbers is that they produce water pollution that must be treated and dealt with. We did not investigate this side of Wet Scrubber systems in detail as our focus was on air pollution control. These systems however suffer common maintenance issues related with pumps and the problems related to the liquid slurry mentioned before. On the following page is a table outlines the available instrumentation and the indicators or particular failures.

Instrumentation	**Indicator**	**Possible Failure**
Pressure Gages ***(Gas Flow)***	High Pressure Difference	Leakage in the system → Check Sealants → Check for structural cracks (Stack, ducts, etc.) → Corrosion Gas Flow Unbalance → Fan malfunction → Check Inlet Duct Particle Build Up
	Low Pressure Difference	Gas Flow Unbalance → Fan malfunction → Check Inlet Duct Leakage in the system → Check Sealants → Check for structural cracks (Stack, ducts, etc.) → Corrosion
Pressure Gages ***(Nozzle Slurry Line)***	High Pressure	Nozzle Plugging Valve Failure
	Low Pressure	Pump Failure Line Leakage Valve Failure
Temperature Monitor	High Temperature	Gas Flow Unbalance → Fan Malfunction → Check Inlet Duct
	Low Temperature	Leakage in the system → Check Sealants → Check for structural cracks (Stack, ducts, etc.) → Corrosion → Check Gas Flow (Fans)
pH Probe	Low/High pH	Check Slurry System → Lime Addition → Pump Failure → Valve Failure → Solids Removal → Corrosion

		→ Flushing/Drains
Humidity Sensors ***(After Mist Eliminator)***	High Humidity	Gas Flow Unbalance → Fan malfunction → Check Inlet Duct Mist Eliminator Failure/Plugging Packed Bed/Plate Failure Nozzle Plugging Check Slurry System → Lime Addition → Pump Failure → Valve Failure → Solids Removal → Corrosion
Vibration/Acoustic Monitors ***(Ducts, Fans, Pumps, etc)***	High/Low Vibration	Corrosion Pump Failure Valve Failure Fan/Local Equipment Failure Leakage in the system → Check Sealants Check for structural cracks (Stack, ducts, etc.)

Figure 15: Wet Scrubber Failure Chart

Obstacles

Over the course of the semester we encountered several obstacles as a team and in smaller groups. Below we have listed several obstacles we came across and the resolutions to each issue. Solid bullets indicate an obstacle and hollow bullets indicate the solution.

Team Obstacles

- There was difficulty contacting control system manufacturers
    - We decided to obtain relevant information from elsewhere
- We initially had unclear goals and sponsor expectations
    - We held a meeting with David Farrel
    - We gathered feedback on the Mid-Term report
- There was disorganized assignment of tasks
    - We appointed team leader
- We had trouble arranging power plant visits
    - We increased the number of people contacting plants and arranging meetings
    - We also increased the frequency of contact
- We had trouble finding valuable information
    - We met with power plant staff
    - We talked to professionals and experts in the respective fields
- Matching availability of team members and getting the power plant visits scheduled accordingly.
    - Came up with the availability chart for general availability
    - Team members volunteered to schedule power plant visits
    - Scheduled multiple power plant power visits so as to get everyone at least one visit.
- Ethical Issues - Look at code of ethics
    - Non disclosure of sponsor
    - Distribution of work
    - Cross cultural communication - See ethics code
- Difficult to find consistent data due to varying plant layouts and sizes

Sub-Team Obstacles

- Wet Scrubbers
    - Finding Wet Scrubbers in service
        - None of the power plant visits involved this system and hence it would be a good recommendation for teams researching on this IPRO during coming semesters to look for some to visit.
        - A power plant with this system was contacted to get theoretical information that substituted for a visit.
    - Team members not showing up for the meeting
- SCRs
    - Finding SCRs in service
    - Choosing a subteam leader
- ESPs/Baghouse
    - Findings Baghouses in service treating exit flue gas

Recommendations:

ESPs and Baghouses

Electrostatic precipitators were found to be the most common emission control system in place in coal-fired power plants. One estimate claims that 90% of power plants in the United States use ESPs to control fly ash. In contrast only 10% of power plants in the US use baghouses. As future emission standards grow more stringent particularly on mercury control, ESPs will become even more dominant in the industry due to their ability to capture mercury and high efficiency. Therefore it is our recommendation that ESPs be a primary target for SmartSignal to apply their technology and to market towards in the industry. Baghouses are more widely used in Europe due to their inclination towards plants designed with a positive pressure. Therefore baghouses would be a better market for SmartSginal's technology overseas.

Selective Catalytic Reducers

Currently, Selective Catalytic Reduction Systems are underutilized in the United States. However, with increasing regulations many power plants will need to retrofit SCRs into their emissions control processes by 2016. We feel that our research on NOx regulations, SCR functionality, and common SCR malfunctions and failures was comprehensive; however, our research on indicators of failure could be much more in depth. We would recommend attempting to do more research on this aspect of SCRs in a few years, by when SCRs will have become more of a standard in power plants, thus making information more easily attainable.   As previously stated above in the results section, we would again like to stress our recommendation of keeping in contact with Babcock Power, the SCR manufacturer from which our subgroup got much of its pertinent information.

Wet Scrubbers

Similarly to SCRs, Wet Scrubbers are not currently in common use as air pollution controls in the United States. As regulations become stricter in 2010, 2012 and in the future, more coal-fired power plants will require Wet Scrubbers serving as FGD systems. Although Wet Scrubbers can be designed to treat fly ash, ESPs are generally considered more efficient and more economical for that purpose. The Spray tower configuration is the most common design for treating sulfur oxides and therefore will be the primary design used in future coal fired power plants. Our recommendation is to focus on more prominent systems currently, but develop a system to monitor FGD systems in the near future. Several power generation companies have installed Wet Scrubbers in flagship plants or in one or two plants in order to prepare for installation throughout their entire operation. These plants, such as We Energies in Pleasant Prairie are a good place to start this process.


courtesy: treehugger.com

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Resources:

Listed below are the expertise and contributions of each member of our team. We did not keep timesheets, however each group member was responsible for presenting the work they had accomplished every week for review. Each team member took meeting minutes on a rotating basis and each member gave several presentations to the group to share their work.

Insiyah Aratsu, Architecture
Logo Design, Wet Scrubber Research, Midterm Presenter, Power Plant Contact, Power Plant Driver, SmartSignal Presenter, Poster/Brochure Design

David Belanger, Civil Engineering
SCR Research, IPRO Presenter, SmartSignal Presenter, Research Compiler, Budget Manager

John Bouikidis, Mechanical Engineering
Wet Scrubber Research, Power Plant Contact, Power Plant Driver, SmartSignal Presenter, Research Compiler

Zachary Capps, Aerospace Engineering
Baghouse Research, Midterm Presenter, Power Plant Contact, Professor Clack Contact, Research Compiler

Cari Hesser, Aerospace Engineering
SCR Research, Research Compiler, Reserve IPRO Presenter, Report Formatter

Sean Irish, Architecture
Logo Design, SCR Research, IPRO Presenter, Poster/Brochure Design, IPRO Presenter

Satyam Kaneria, Electrical Engineering
iGroups Moderator, ESP Research, Research Compiler, IPRO Presenter

Brett McQuillan, Architectural Engineering
Team Leader, Wet Scrubber Research, Midterm Presenter, Research Presenter, Research Compiler, Report Compiler

Lavesh Mohinani, Electrical Engineering
Project Plan Compiler, ESP Research, Professor Clack Contact, Research Compiler, Report Formatter

Jay Patel, Computer Science
iGroups Moderator, Gantt Chart Moderator, Wet Scrubber Research, IPRO Presenter, Research Compiler, Food Coordinator

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A SCR manufacturer from which the SCR subgroup obtained the majority of its information

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Midwest Generation

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Dr. Herek Clack

For his expertise in Electrostatic Precipitators

Dr. Noll

For his guidance in regulations and general design practices

Scott Patulski

A We Energies employee that provided relevant information about system costs, life expectancy, maintenance issues, and instrumentation for all four systems that our IPRO was researching

SmartSignal

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