Enpro 356
Evaluating the Commercial Potential
Of
-IIT's Mercury Pollution Prevention Technology

~~Mid-term Progress~~ Final Report

www.iit.edu/~ipro356s05

Sponsor
Sargent & Lundy LLC
and the Ed Kaplan Entrepreneurial Studies Program

Group Members

Chris MacDougall — Noël Wessely
Kheim Nguyen — Byung Kim
Matthew Dabney — Wen-Ya Chang

Formatted: Different first page header
Formatted: Font: 16 pt
Formatted: Centered
Formatted: Font: Not Bold, Underline
Formatted: Centered
Formatted: Font: Times New Roman, 12 pt
Formatted: Font: (Default) Times New Roman, 12 pt
Formatted

Faculty Adviser
Myron Gottlieb

Formatted: Right: 0.25"

Formatted: Font: Times New Roman, 12 pt

Formatted: Font: Times New Roman, 12 pt

Formatted: Right: 0.25"

Table of Contents

I. Introduction-- page 3
II. Project Purpose--- page 3
III. Project Research Methodology-------------------------- page 4

1. Regulation --- page 4
2. Virtual Sorbent Beds (VSB) ---------------------- page 5
3. Competitions --- page 7
4. Market --- page 14
5. Market Strategy ------------------------------------ page 19
6. Finances -- page 20
7. Risks --- page 22
8. Assumptions -- page 25

IV. Assignments -- page 28
V. Obstacles -- page 28
VI. Conclusion -- page 28
VII. References --- page 29
VIII. Exhibits -- page 30

Formatted: Right: 0.25"
Formatted: Font: Not Bold
Formatted: Font: Not Bold
Formatted: Font: Not Bold
Formatted: Right: 0.25"

~~Updated Objectives~~Introduction

~~Our objective in this IPRO is to develop a business plan for Dr. Clack's VSB technology. The VSB is designed to remove mercury pollution from power plant emissions in a cost-effective manner. In developing this business plan, we are looking at the marketing strategy, market size, finances, and competition for this product. We are also looking at the government regulations governing this type of technology, at the business risks in developing the VSB and how to market it. The last objective for this IPRO is to develop a set of objectives and a path forward for any future IPROs on this topic. With this information we should have a business plan for developing and selling Dr. Clack's VSB technology.~~

Mercury population is a problem that is currently facing our world. The element of mercury is a persistent, bio-accumulative nerve toxin. Mercury works its way up the food chain, yielding in higher and higher dosage for each successive consumer. When it enters the human body it can directly affect the brain and in sufficient doses it can kill. Every year the United State's coal fire power plant industry releases 48 tons of mercury in airborne emissions. The EPA states that a safe amount of mercury to consume is .1 of a millionth of a gram per day per kilogram body weight. This means that 4 tablespoons distributed among the entire population of Canada (32 million people) would be enough for the entire population to reach a toxic level of mercury.

In order to provide an answer to this growing concern, the United States government has released a set of regulations that will require coal fire power plants to reduce their amount of emissions. Done over several years in two separate increments, the regulations will require a reduction of around at least 70% of mercury in emissions. These regulations are a reflection of growing concerns to prevent the side effects that occur every year due to mercury poisoning.

The regulations, while limiting emissions every year, place no regulation on the technology that reaches the solution. This creates the opportunity for a highly effective technology to enter the market. The Cap-and-Trade system that the regulations implement also creates a situation in which power plants may actually seek to go beyond the regulation cap in some plants in order to meet regulations in others. This presents an opportunity and a market for the Virtual Sorbent Bed (VSB).

Project Purpose

Our objective in this IPRO is to develop a business plan for Dr. Clack's VSB technology. In developing this business plan, we are looking at the marketing strategy, market size, finances, and competition for this product. We are also looking at the government regulations governing this type of technology, at the business risks in developing the VSB and how to market it. The last objective for this IPRO is to develop a set of objectives and a path forward for any future IPROs on this topic. With this information we should have a business plan for developing and selling Dr. Clack's VSB technology.

Formatted: Right: 0.25"

Formatted: Font: 14 pt

Formatted: Font: 14 pt

Formatted: Right: 0.25"

Formatted: Right: 0.25"

Formatted: Right: 0.25"

Formatted: Right: 0.25"

Project Research Methodology

Formatted: Font: 14 pt, Font color: Black

Formatted: Font: 14 pt

1. Regulation

On March 15, 2005, the Environmental Protection Agency released the Clean Air Mercury Rule, a first-time effort to limit the production of mercury in coal-fired power plants. A cap-and-trade system was instituted as the most cost-effective means of reducing mercury emissions for larger electric utility units. Though the larger units output more mercury, the EPA finds it more likely that "these larger units will over-control their emissions and sell allowances, than to not control and purchase allowances. Under the cap-and-trade system, the allowances are transferable and can be traded among regulated facilities.

The limitations of mercury emissions per generating unit are broken up per coal type and are as follows:

Bituminous units		0.0026 ng/J	21×10^{-6} lb/MWh
Subbituminous units	Wet FGD	0.0055 ng/J	42×10^{-6} lb/MWh
	Dry FGD	0.0103 ng/J	78×10^{-6} lb/MWh
Lignite units		0.0183 ng/J	145×10^{-6} lb/MWh
Coal refuse units		0.00017 ng/J	1.4×10^{-6} lb/MWh
IGCC units		0.0025 ng/J	20×10^{-6} lb/MWh

These values can be compared to the mercury content of coals found in a report by the EPA:

Bituminous coal	2.9×10^{-5} lb/MWh
Subbituminous coal	2.0×10^{-5} lb/MWh
Lignite coal	3.6×10^{-5} lb/MWh

The EPA intends for a first phase cap of 38 tons per year in 2010 and then a decrease to 15 tons of mercury produced per year in 2018.

The CAMR lists that all coal-fired generators that fire more than 73 megawatts of power or sell more than 25 megawatts of electrical output and more than one-third of their potential output capacity to any utility power distribution system. Also, all generators must comply with the new regulations, regardless of age. No provisions or grandfathering were made regarding the age of a generating unit, thus increasing the potential market size of the VSB.

2. Virtual Sorbent Beds (VSB)

Formatted: Right: 0.25"

2.1 Overview of VSB

Virtual Sorbent Beds (VSB) is specifically developed to increase the efficiency of mercury removal from coal combustion exhaust (flue gas).

VSB builds on two proven technologies, Activated Carbon Injection (ACI) and Electrostatic Precipitator (ESP). Current sorbent injection and ESP technologies work by injecting a charged powder, specifically activated carbon, into the flue gas as they pass through the electric field in the ESP. As sorbent travels along with the flue gas, pollutants in the flue gas adsorb to the charged sorbent, which are then removed from the system.

By introducing an AC-induced electric field, the traveling behavior of the sorbent is altered in VSB. Specifically, VSB increases both the traveling time and path of the charged sorbent in the system. Essentially, this extra step increases the probability of particulate adsorption, including mercury pollutant.

2.2 Technical Advantages

VSB also offers several technical advantages over other technologies. These advantages include dense sorbent loading, high gas-particle relative motion, no pressure drop and elimination of jet mixing limitations.

- Dense sorbent loading: Virtual sorbent beds produce a much denser sorbent suspension than that which results from conventional sorbent injection. The significance is simple reaction kinetics: in a reaction with two or more reactants, the more you have of either, the faster the reaction proceeds. VSB increases the carbon per unit volume suspended in the mercury-laden gas, thereby increasing the rate at which mercury is adsorbed.
- High gas-particle relative motion: An increase in relative velocity between the sorbent and gas-phase absorbate greatly enhances the adsorption process as compared to conventional ESP technology.
- No pressure drop: VSB poses no pressure drop in the system. Other technologies, especially fabric filters, produce a pressure drop of 5-6atm, which must be overcome by large fans. Running these fans costs significantly more than charging the plates of an ESP.
- Eliminates jet mixing limitations: Jet mixing decreases residence time, which is critical for adsorption. The larger the residence time, the more efficient the sorbent is at removing mercury. The VSB eliminates this restriction.

2.3 Other Applications

Virtual Sorbent Beds, originally developed to remove part-per-billion concentrations of mercury from coal combustion exhaust, is flexible and suitable enough to be applied to other fields, including chemical detection.

VSB is capable of detecting airborne threats when applied as a biochemical sensor. Any chemical/reaction process that involves a gaseous reactant and either a solid reactant or a

Formatted: Right: 0.25"
Formatted: Font: (Default) Times New Roman, 12 pt
Formatted: Font: (Default) Times New Roman, 12 pt
Formatted: Font: (Default) Times New Roman, 12 pt, Font color: Black
Formatted: Font: Bold
Formatted: Font: (Default) Times New Roman, 12 pt
Formatted: Font: Bold
Formatted: Font: (Default) Times New Roman, 12 pt, Not Bold
Formatted: Font: (Default) Times New Roman, 12 pt, Font color: Black
Formatted: Font: (Default) Times New Roman, 12 pt, Not Bold, Font color: Black
Formatted: Bullets and Numbering
Formatted: Font: (Default) Times New Roman, 12 pt, Font color: Black
Formatted: Font: (Default) Times New Roman, 12 pt, Not Bold, Font color: Black
Formatted: Font: (Default) Times New Roman, 12 pt, Font color: Black
Formatted: Font: (Default) Times New Roman, 12 pt, Not Bold, Font color: Black
Formatted: Font: (Default) Times New Roman, 12 pt, Font color: Black
Formatted: Font: (Default) Times New Roman, 12 pt, Not Bold, Font color: Black
Formatted: Font: (Default) Times New Roman, 12 pt, Font color: Black
Formatted: Font: Bold
Formatted: Font: (Default) Times New Roman, 12 pt
Formatted: Font: Bold
Formatted: Font: (Default) Times New Roman, 12 pt, Not Bold
Formatted: Font: (Default) Times New Roman, 12 pt, Font color: Black
Formatted: Right: 0.25"

solid catalyst can be applied with VSB. VSB has the most in common with a fluidized bed.

2.4 VSB's Phase

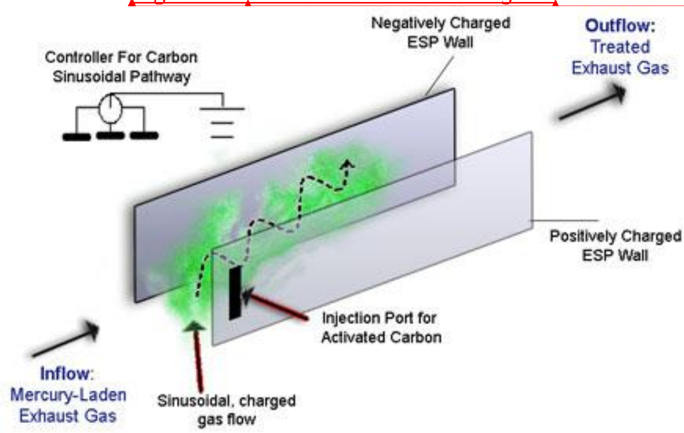
VSB is still in its designing and development phase. A bench-scale virtual sorbent bed apparatus has been built to obtain proof-of-concept results.

To better understand how VSB works, examine the following diagram, which shows the basic gas-flow behavior in the ESP along with VSB-enabled technology.

The Process

1. Mercury contaminated gas enters the ESP.
2. Electrically charged Activated Carbon (AC) is driven in a dense "bed" from one ESP wall to the other.
3. Pathway of AC bed is controlled sinusoidally.
4. Hg contained in the gas is adsorbed onto the AC.
5. The Hg-laden AC is collected
6. Hg-laden AC is either recovered or disposed as a hazardous waste.

Figure V2. *Sinusoidal Gas Flow Diagram*



A patent for VSB was submitted on March 2005.

2.5 VSB Research and Development Milestones

- Aug 1999 - Sept 2002 – *Familiarization with technological challenge of mercury emissions control*

Formatted: Right: 0.25"
Formatted: Font: (Default) Times New Roman, 12 pt
Formatted: Font: (Default) Times New Roman, 12 pt
Formatted: Font: (Default) Times New Roman, 12 pt, Font color: Black
Formatted: Bullets and Numbering
Formatted: Font: (Default) Times New Roman, 12 pt, Not Bold
Formatted: Font: (Default) Times New Roman, 12 pt, Not Bold
Formatted: Font: (Default) Times New Roman, 12 pt, Not Bold, Font color: Black
Formatted: Font: (Default) Times New Roman, 12 pt, Not Bold
Formatted: Font: (Default) Times New Roman, 12 pt, Not Bold
Formatted: Font: (Default) Times New Roman, 12 pt, Not Bold
Formatted: Font: (Default) Times New Roman, 12 pt, Font color: Black
Formatted: Font: Bold
Formatted: Font: (Default) Times New Roman, 12 pt
Formatted: Font: (Default) Times New Roman, 12 pt
Formatted: Font: (Default) Times New Roman, 12 pt, Font color: Black
Formatted: Bullets and Numbering
Formatted: Right: 0.25"

- September 2002 – *Idea conception*
- June 2003 – *White paper sent to industry colleagues (EPRI, Southern Company)*
- Fall/Winter 2003 – *Prototype constructed*
- September 2003 – *Discussion with IIT Prof. Victor Perez-Luna re: integrating VSB into biosensor design*
- December 2003 – *Research proposal submitted to Dept. of Energy (with General Electric and Penn State Univ.)*
- June 2004 – *Preparation of Invention Disclosure Document*
- October 2004 – *Successive NSF contracts awarded for continuing research*
- November 2004 – *First prototype tests*
- March 2005 – *Initiation of patent application*
- Spring 2005 - *Enpro 356 business potential evaluation of VSB*

Future plans for VSB development are contingent on obtaining funding to support the research. With funding, proof-of-concept could be completed in 1 year, followed by a 2-3 year pilot-scale test at a power plant.

3. Competitions

3.1 Overview on Competition

There are several other technologies being developed for mercury removal from power plant emissions. These include both new technologies that have never been commercially used before and older technologies that are currently being used to control other forms of pollution but have not been used for mercury yet. Most of the new technologies are in the pilot testing stage. This means that they are being tested in one or two power plants for a short period of time (6-12 months). Some of the older technologies are currently installed in power plants to control fly-ash while the remainder are used in SOx and NOx control.

In examining these potential competitors, we looked at efficiency as the most important criteria in determining their potential. Since the intended market for the VSB is after the implementation of the second round of emission controls, a minimum efficiency of 70% was used to determine if another technology would be competitive with the VSB. Table 1 shows the possible competitors and their efficiencies.

Table 1

Technology type (abrreviation)	Efficiency in %
Hot-side Electrostatic Precipitator (H-ESP)	15
Cold-side Electrostatic Precipitator (C-ESP)	38
Fabric Filter (FF)	70
Spray Dryers Absorbers (SDA) +FF	98
FF+H-ESP	90
FGD+C-ESP	80
FGD+ H-ESP	45

Formatted: Right: 0.25"

Formatted: Font color: Black

Formatted: Indent: First line: 0"

Formatted: Right: 0.25"

FGD+Wet Scrubber (WS)	0
Selective Catalytic Reduction (SCR)	15-39% increase, used in combination with collection device
ECO Powespan	80+
GSA FLSmith/Airtech	50-90
LoTOx BOC Gases	90+
Mitsui BF process (Marsulex)	85-90

Note: the SDA+FF technology is a sorbent injection technology

The SCR in Table 1 is not a mercury pollution control device in and of itself. It helps other technologies remove mercury pollution by converting elemental mercury to oxidized mercury. The oxidized mercury is much easier to remove than the elemental. The benefit gained by having an SCR varies drastically from plant to plant. The factors that affect this include current mercury content in the gas, age of the catalyst in the SCR, age of the plant and the type of capture device used to capture the mercury.

Among the older technologies on this list, the top competitors are the FGD+C-ESP and the SDA+FF. The SDA+FF is a form of sorbent injection where the sorbent is captured by the fabric filter. This technology will be examined in depth later. The FGD+C-ESP is another combination technology. The advantage here is that the C-ESP is already installed in the power plant. An FGD works by injecting a limestone slurry into the gas stream. The mercury is adsorbed to the slurry. The slurry is then dried and collected by the ESP. This combination is currently in use in some power plants to capture Sox, which is what the FGD was originally designed for. The problems with this method include cost and its ability to be retrofitted. It is expensive to retrofit this technology because the ESP needs to be designed to handle the additional load. Installing a new FGD costs $35-75 million, while installing a new ESP costs $40-60 million.

3.2 Competitor

Conventional Limestone/Lime Flue-Gas Desulfurization

Formatted: Right: 0.25"

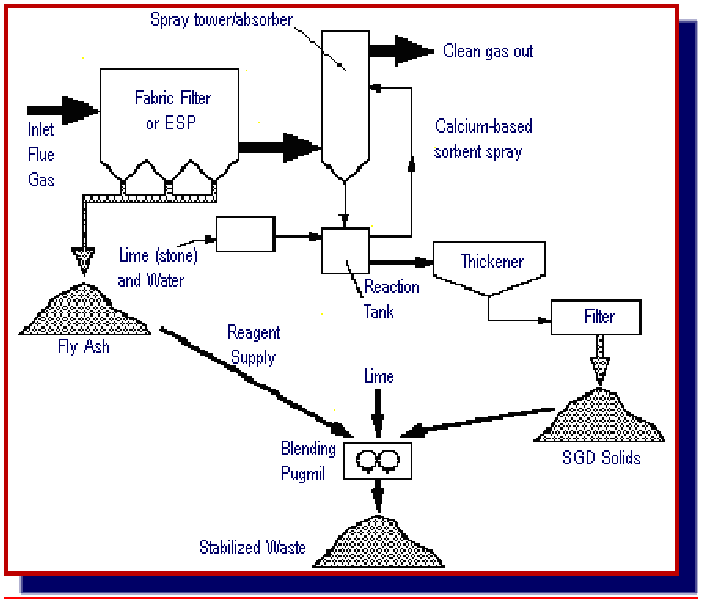
Formatted: Font: Bold

Formatted: Font: Not Bold, Underline

Formatted: Underline

Formatted: Right: 0.25"

Formatted: Right: 0.25"



Some of the technologies in Table 1 can also benefit from sorbent injection technologies. In particular, the C-ESP and the FF would benefit with this addition. The H-ESP would not benefit from this because sorbent technologies work better at lower temperatures. The following section evaluates the benefits and problems with sorbent injection and their applications with C-ESPs and FFs.

Sorbent Injection

Formatted: Font: 12 pt, Not Bold, Underline

The advantages of using sorbent injection include the following:
- low capital cost
- easy to retrofit
- minimum impact on plant operation
- mercury removal rate proportional to injection rate
- applicable to all coals
- sorbent collected with fly ash

The disadvantages of this technology are discussed later.

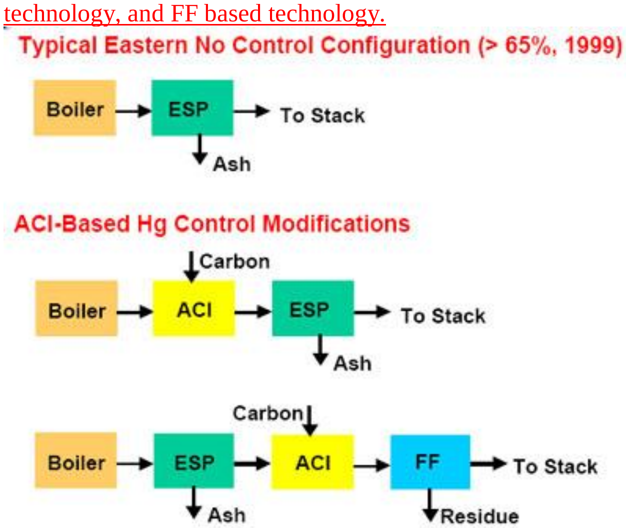
Activated Carbon

Activated carbon (AC), like many other sorbents, is good for adsorbing Hg from flue gas. Activated carbon is injected into the flue gas through a spray dryer or duct injection and is captured by the electrostatic precipitator or fabric filter system. Various tests show that AC can remove up to 90% of total Hg in the flue gas.

Formatted: Right: 0.25"

Formatted: Right: 0.25"

The following diagram shows where AC is injected and how the whole scheme of filtering flue gas works on a block diagram perspective. The diagram shows three scenarios: no control technology (which does not include sorbent injection), ESP based technology, and FF based technology.



Sodium Tetrasulfide

Sodium tetrasulfide, Na_2S_4, has been used as a sorbent to remove mercury from flue gas in a number of waste-to-energy plants. By converting vapor-phase mercury to an insoluble solid, it may be removed in a bag house or electrostatic precipitator typically found in a coal-fired power plant. In some pilot-test cases, efficiency can be as high as 98%.

Mercury Capture Process

Mercury Capture Process is a proprietary method that uses noble metal gases to adsorb Hg. Lab tests of alumina-supported gold showed 95% removal of gaseous mercury.

Amended Silicate

Amended silicate is a good substitute for AC for several reasons. The amended silicates have shown improvement factors of 1.5–2 in controlling Hg emissions over activated carbon from sub bituminous coal testing in a pilot-scale test. Amended Silicate is an inexpensive, non-carbon substrates amended with mercury-binding sites.

Disadvantages of Sorbent Injection

Sorbent Injection is done in conjunction with a particulate pollution control device. This is generally either a cold-side ESP or a fabric filter. These devices collect the sorbent as

Formatted: Right: 0.25"

Formatted: Right: 0.25"

well as the fly-ash that they were initially designed to collect. Table 2 shows the percentage of power plants that have ESPs installed and the percentage that have FFs.

Table 2

Hot-side Electrostatic Precipitator	10.7
Cold-side Electrostatic Precipitator	71.3
Fabric Filter	9.8

Since most power plants already have ESPs installed, they would prefer to have the sorbents captured in this manner. Unfortunately, most ESPs are designed to operate near their limits for particulate control. This means that they may not be able to handle the additional load of the sorbent. This still leaves the option of installing the fabric filter, but this option has drawbacks as well. The cost of installing a new fabric filter is between $50-70 million.[3] In addition to this installation cost, the fabric filter has a high operating cost. The fabric in the fabric filter causes a pressure drop in the stack. This pressure drop needs to be overcome by fans, which cost a substantial amount of money to run.[3] In spite of these disadvantages; the fabric filter with sorbent injection is considered one of the stronger competitors on the market.

The new technologies in Table 1 are still under development and there is little data concerning costs and other disadvantages of the technologies. The most promising of these technologies is the Electro-Catalytic Oxidation (ECO) technology. It is an integrated multi-pollutant control technology that reduces emissions of NO_x, SO_x, fine particulate matter, and mercury from the flue gas of coal-fired power plants. The process also produces a valuable fertilizer co-product that reduces operating costs and avoids landfill disposal of waste. Pilot testing has shown that the ECO process consistently achieves 80 to 90% capture of the mercury.[6]

The following diagram shows the ECO process in three steps.

Formatted: Right: 0.25"

Formatted: Right: 0.25"

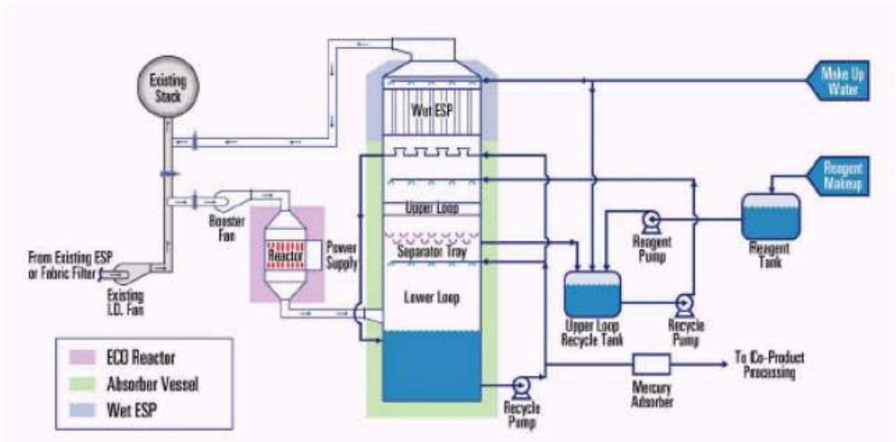
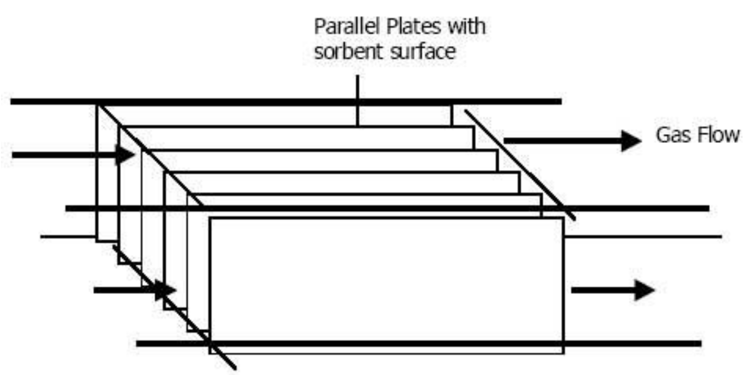


Figure. *Schematic Diagram of Electro-Catalytic Oxidation (ECO) Process.*

There are two other new technologies that are not listed in Table 1. These two technologies are also showing promise, but their efficiencies are too variable to be included in Table 1. The technologies are the MerCap technology and the Advanced Hybrid™ filter technology.

Mercury Capture Process

Mercury Capture Process is a proprietary method developed by Electric Power Research Institute (EPRI) that uses noble metal gases to adsorb Hg. In this process a rigid, mercury adsorbing sorbent-coated structure is placed in the duct. Mercury is removed from the flue gas as it flows past the rigid structure (see the Figure below). When the plates and tubes are saturated with mercury, they can then be removed as a cartridge or regenerated in-situ.[8] The mercury can be recovered and isolated in this process, as opposed to other processes that capture mercury as a waste. Lab tests of alumina-supported gold showed 95% removal of gaseous mercury.



Formatted: Right: 0.25"

Formatted: Right: 0.25"

Figure. *MerCap™ Schematic.*

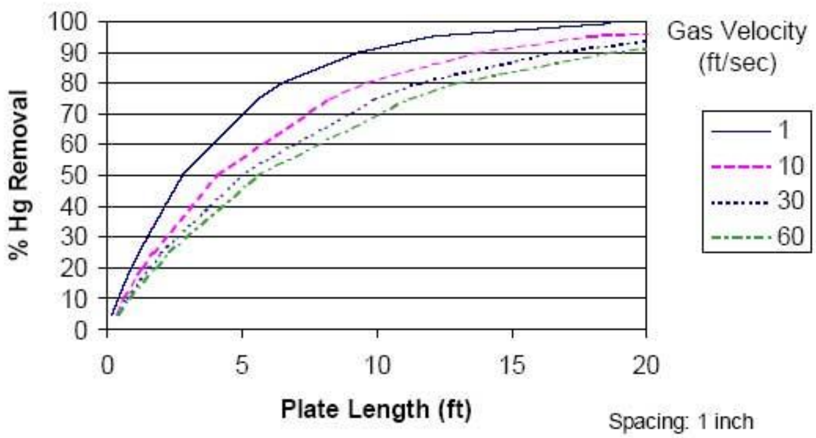


Figure. *MerCap™ Hg Removal Efficiency vs. Plate Length*

Amended Silicate™ Technology

Amended silicate, developed by ADA Technologies in conjunction with CH2M Hill, is a good substitute for AC for several reasons. The amended silicates have shown improvement factors of 1.5–2 in controlling Hg emissions over activated carbon from subbituminous coal testing in a pilot-scale test. Amended Silicate are inexpensive, non-carbon substrates amended with mercury-binding sites. Some advantages of Amended Silicate include the following:

- Cost-competitive with other sorbent materials (e.g., activated carbon)
- Reliable operation using demonstrated injection system equipment
- Does not affect the ability of the fly ash to be sold as a concrete additive.
- High mercury capture capacity ? several times that of activated carbon. Amended Silicates sorbents provided 70%-96% mercury capture at injection rates of 1.6-9 lb/MMACF in pilot testing at an operating power plant.

Formatted: Bullets and Numbering

Advanced Hybrid Filter Technology

Formatted: Font: 12 pt, Not Bold, Underline

The Advanced Hybrid™ filter technology combines the best aspects of two existing fly ash-capturing technologies: electrostatic precipitators and GORE-TEX® membrane filter bags in a new and highly efficient way. This technology is still under testing. Primitive data suggested that with current sorbent injection of carbon at 1.5 lb/mact removes 50-90% of Hg. The following diagram shows the schematic of the Hydrid Filter.

Formatted: Right: 0.25"

Formatted: Right: 0.25"

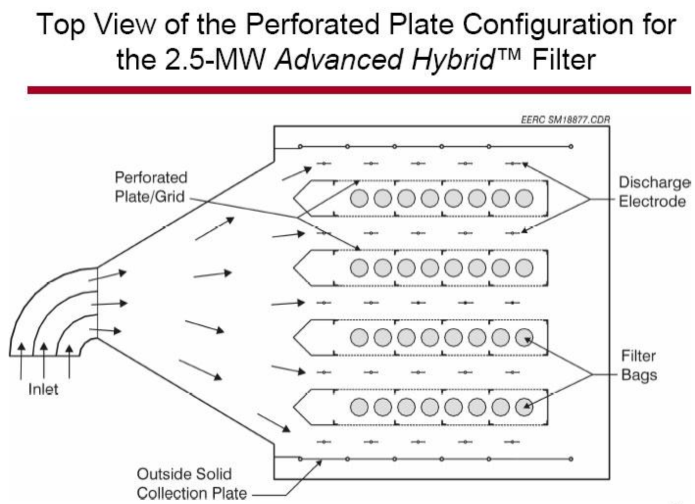


Figure. *Advanced Hybrid Filter Schematic.*

The top mercury pollution control technologies that are being examined for power plant emission control are: FGD+C-ESP, SDA+FF, ECO, *MerCap*™ and *Advanced Hybrid Filter.* These five technologies will be competing for the same market as the VSB. The VSB will need to be better than these technologies in the following critical areas: efficiency, cost and the ability to be retrofitted.

Formatted: Indent: Left: 0"

3. Market

Formatted: Font: Not Bold, Font color: Black

A new market for the VSB was created by new regulation on mercury pollution from power plants, which was released in March 2005. A Market overview and an estimate of market size will be provided below to examine the potential revenue for the project.

4.1 Market Overview

4.1.1 Regulation Driven Market

Formatted: Outline numbered + Level: 2 + Numbering Style: 1, 2, 3, … + Start at: 1 + Alignment: Left + Aligned at: 0" + Tab after: 0.25" + Indent at: 0.25"

Formatted: Outline numbered + Level: 3 + Numbering Style: 1, 2, 3, … + Start at: 1 + Alignment: Left + Aligned at: 0" + Tab after: 0.5" + Indent at: 0.5"

A new federal regulation was released in March 2005, mandating coal-fired power plants to reduce mercury concentration of exhaust to a certain level. Coal-fired power plants have to seek new solutions to achieve the required levels of mercury emissions.. Consequently, a new, regulation driven market for mercury removal technology was created. The VSB should, once developed, efficiently remove mercury generated by coal-fired generators, and provide an economical solution for coal-fired power plants. Therefore, the VSB should be able to compete in the new market.

Formatted: Right: 0.25"

Formatted: Right: 0.25"

The characteristics of a regulation driven market are quite different from those of a regular market. The most significant distinctness is that in a regulation driven market, companies are mandated to pay for required solutions. In other words, companies can't avoid expenses for new solutions. Thus, when deciding the market size of the mandatory market, the estimate of requirements from bottom up is more appropriate than the estimate of purchasing power from top down.

4.1.2 Quick Facts for Businesses of Coal-Fire Power Plants

Formatted: Bullets and Numbering

- **Total Revenue Generated by Coal-fired Power Plants**

Formatted: Bullets and Numbering

Total Revenue generated by coal-fired power plants is used to measure the business size of all power plants in the United States. Since coal-fired power plants supply part of electricity, the revenue generated by coal-fired power plants was estimated by calculating the capacity percentage coal-fired power plants accounting for and the total revenue of all electricity generation businesses.

With the assumption that the capacity percentage (32.53%)[1] from coal-fired plants in 2003 was the same with that in 2000, the estimated revenue generated by coal-fired power plants in 2000 was around 95.6 billion dollars. **Exhibit 1** shows the total revenue of all electricity generation businesses in 2000. **Exhibit 2** shows existing capacity by energy sources in 2003. **Exhibit 3** shows the estimated revenue generated by coal-fired power plants.

- **Units of coal-fired power plants**

Formatted: Bullets and Numbering

In 2003, there were 200 companies, which owned 422 coal-fired power plants, produced 964,049 Megawatts electricity (32.53% of all electricity capacities). **Exhibit 4** shows quick facts of coal-fired power plants.

- **Current Capital Expenditure (of power plants) for Air Pollution Abatement**

Formatted: Bullets and Numbering

Total pollution abatement capital expenditures of coal-fired power plants for new structures and/or equipments during 2003 were around 2 billion dollars (2,836,775,000), while those of all electricity power plants were 3,889,466,000 dollars. (Coal-fired power plants accounted for about 73% of all air pollution abatement expenditures of all power plants)[2]

4.2 Market Size and Segmentation

Formatted: Bullets and Numbering

Since the VSB has unique competency for Plants with Electrostatic Precipitations (ESP), ESP usage is considered when estimating the market size for the VSB. In addition, coal type is taken into account when segmenting the markets.

4.2.1 Target at Electrostatic Precipitation (ESP) Users

Formatted: Bullets and Numbering

[1] Source: Energy Information Administration, Form EIA-767, "Steam-Electric Plant Operation and Design Report."

[2] Source: Energy Information Administration, Form EIA-767, "Steam-Electric Plant Operation and Design Report."

Formatted: Right: 0.25"

• **VSB is an attractive alternative for ESP Users**

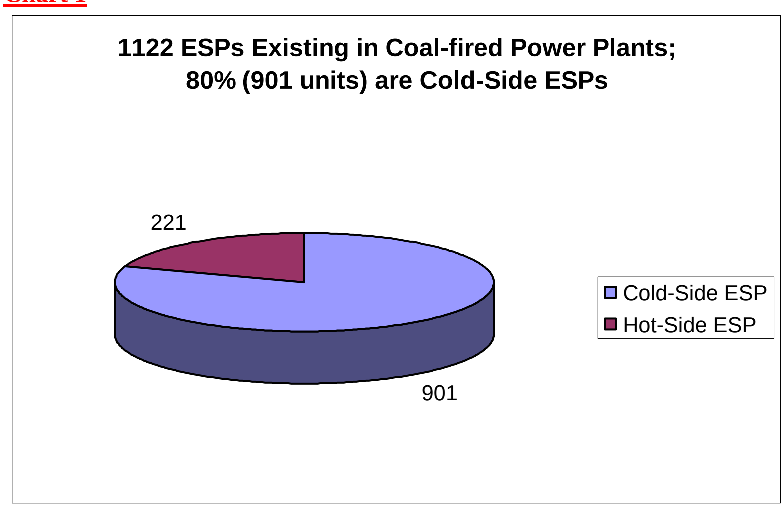
Virtual sorbent beds (VSB) are compatible with established technology, Electrostatic precipitation (ESP). VSB and ESPs are based on the same technology; They both charge particles of carbon and pull them out of the air stream via electric fields. **Exhibit 5** shows schematics of ordinary electrostatic precipitation compared to virtual sorbent bed. For existing ESP operators, a VSB retrofit will be an attractive alternative to installing a redundant downstream bag house for mercury adsorption. In addition, configuring a VSB as an extension to an existing ESP allows the fly ash to be collected separately from the injected sorbent. This preserves the value of low-carbon ash, which is sold to cement companies as filler, and allows custom, regenerable sorbents to be used for mercury capture.

In general, Virtual sorbent Beds (VSB) are an attractive mercury pollution prevention alternative for existing Electrostatic precipitation (ESP) operators, since these two technologies are compatible and can create significant economical savings through cooperation. (**Exhibit 6** lists major ESP companies.)

• **1122 ESPs Existing in Coal-fired Power Plants**

There are two types of ESPs existing in coal-fired power plants: cold-side and hot-side ESPs. 1122 ESPs existing in coal-fired power plants include 901 cold-side ESPs (80%) and 221 hot-side ESPs (20%).

Chart 1



4.2.2 The main market segments for VSB

• **.ESP Types**

Formatted: Right: 0.25"
Formatted: Bullets and Numbering
Formatted: Bullets and Numbering
Formatted: Bullets and Numbering
Formatted: Bullets and Numbering
Formatted: Right: 0.25"

There are two types of ESPs : Cold- and Hot-Side ESP used to remove particles from the exhaust in power plants. Theoretically, the VSB can work well with both types. However, the VSB with Cold-Side ESP can achieve higher efficiency, because at temperature of 130-170C, typical of Cold-Side ESP, elementary Hg is oxidized to Hg^{2+}, which will be attracted to charged carbon and then collected. Therefore, in the first stage, we will target at Cold-Side ESP users.

- **Coal Types**

According to the Clean Air Mercury Rule, which was released on March 15, 2005, the limitations of mercury emissions are broken up per coal type. In addition, different coals contain different amounts of mercury. Therefore, coal types are considered when segmenting the market. Bituminous coals are used mostly in the market, and thus, we will target at plants with the coals.

- **Target Segments**

In conclusion, the first target segment for the VSB will be the coal-fired power plants that use Cold-Side ESP and bituminous coals, and the second segment will those ones that use Cold-Side ESP and subbituminous coals.

Chart 2

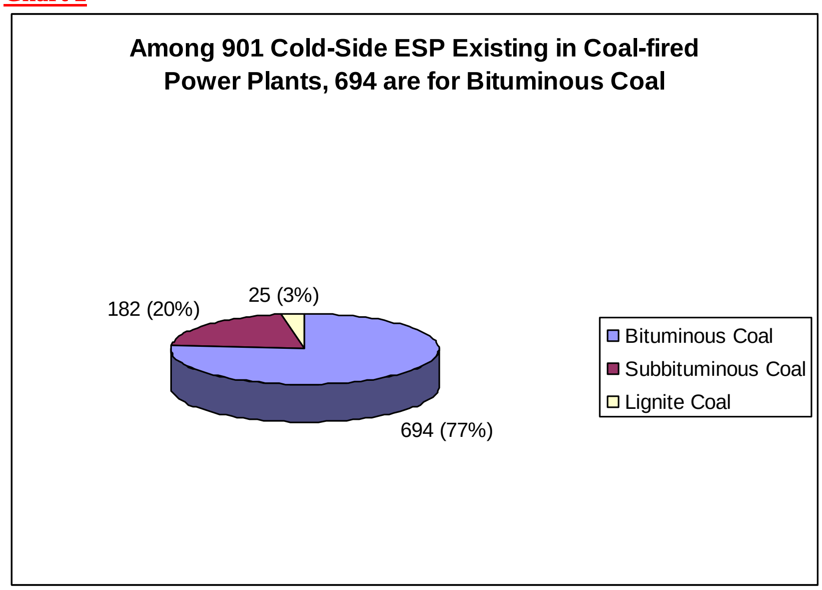


Chart 3

Formatted: Right: 0.25"
Formatted: Bullets and Numbering
Formatted: Bullets and Numbering
Formatted: Right: 0.25"

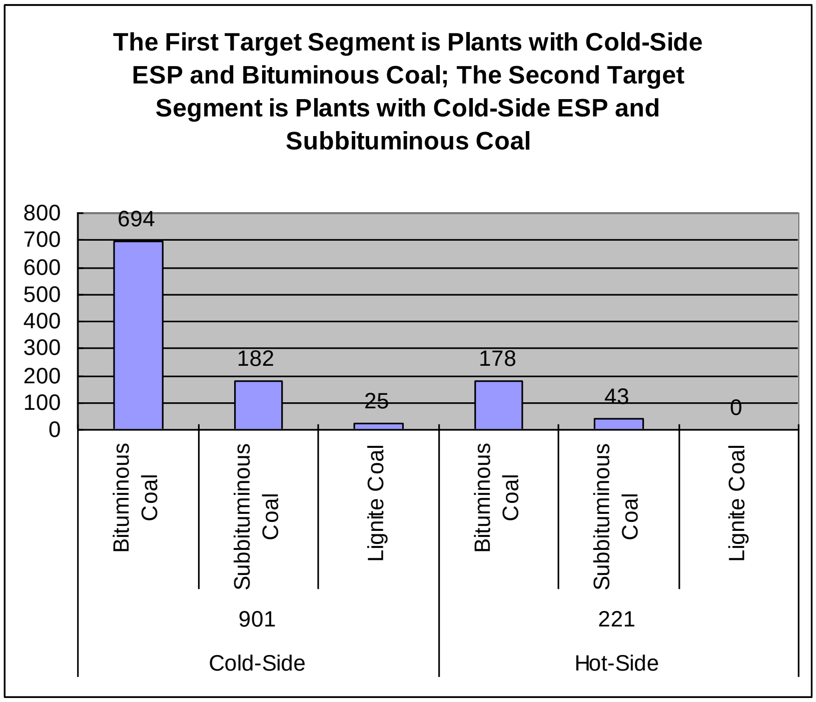


Table 1: Customer Segmentation

Total ESP at Coal-Fired Power Plants	**1122**	Cold-Side	**901**	Bituminous Coal	**694**
				Subbituminous Coal	**182**
				Lignite Coal	25
		Hot-Side	221	Bituminous Coal	178
				Subbituminous Coal	43
				Lignite Coal	0

4.3 Characteristics of the Market

4.3.1 A Mandatory Market

The market is created by the new regulation, the Clean Air Mercury Rule (CAMR); all the power plants have to seek for solutions to meet the new mercury limitations. This mandatory market is a pull market, in which new products are required and requested. This market also indicates that an economical solution, which will minimum operation costs of mercury removal, such as the VSB, can sell at high prices. The manufacture costs of VSB are estimated low, and thus, the VSB will have potential high profit margins.

4.3.2 Development and Marketing Timing

Formatted: Right: 0.25"

Formatted: Bullets and Numbering

Formatted: Right: 0.25"

According to CAMR, EPA allows coal-fired power plants to cap emissions in two phases. The first cap in 2010 would be achieved as a co-benefit of facilities installing SO_2 and NOx emissions control equipment to comply with Clean Air Interstate Rule (CAIR) because these controls can help reduce mercury. The second phase cap, in 2018, will reduce coal-fired power plant emission to 15 tons. This approach realized a total reduction in mercury emissions of nearly 70%.

Based on the fact stated above, it is assumed that the time period when coal-fired power plants would purchase equipments to remove mercury efficiently would be from 2010-2018. Therefore, the VSB has to complete its development plan before 2010 to be the first in the market. VSB is now, in 2005, at the laboratory stage, and has to be visible in the market and to do large-scale demonstration before going to market. Year 2010 will be five years from now. If the VSB can start the commercialization processes, it should be able to be in the market in the right timing.

5. Market Strategy

The VSB market strategy involves a limited market with the possibility for a high market penetration. The target market is regulation-driven, based on regulations released on March 15th, 2005 which require all coal fire power plants to reduce the amount of mercury being released each year. This creates a need for a technology that can efficiently reduce mercury emissions involved in a VSB, and thus creates a market of 422 power plants. By focusing mainly on power plants with ESP technology already installed, the team offers an add-on technology that hopes to show high efficiencies at lower installation rates. The specifics of the market segmentation are further described in the "Market Size" section.

The ESP technology of the VSB holds the promise of being one of the few technologies that will be able to reach higher levels of efficiency in removing mercury from the emissions without unnecessary side effects. Offering a potentially very high efficiency rate (over 90%) will allow sale to power plants that wish to meet regulation early, with additional capacity to avoid any complications. With the cap-and-trade regulation allowance (see regulations section) companies have the option of making one plant operate at well above the required efficiency, while another plant reaches lower level. This trading system also makes the VSB a desirable alternative as it gives the coal companies options for plants that will be more expensive to regulate. The VSB technology also avoids common side effects that some of the alternative offer, such as large pressure drops or increases in other pollutants. Finally, and perhaps most significant, the VSB is designed as a modular add to an existent component of a large number of coal plants in America, an electrostatic precipitator. This would mean that the installation would be relatively simplistic, and would also require less space than an additional bag house or scrubber system.

Formatted: Right: 0.25"
Formatted: Font: Bold
Formatted: Font: Bold
Formatted: Line spacing: single
Formatted: Right: 0.25"

Formatted: Right: 0.25"

The competitive edge offered by the VSB technology is based on the analysis offered from the initial research in the technology. In order to fully understand the product's capability, it is understood that further research will be necessary.

In the coal-fire power plant market, the individual power plants typically decide upon one solution path and don't vary from it. Specifically, power plants that have decided to invest in a bag house are unlikely to change their mind and then attempt to implement an ESP; the opposite is also true- those that have invested in an ESP are unlikely to invest in a bag house alternative. Due to this fact, the EnPRO team has decided that it would be best to focus the marketing efforts on power plants with electrostatic precipitators

Given the current resources of the team, and the level the technology is current at, it is seen as a better alternative to sell the product through another vendor; an Architectural Engineering Firm. This strategy offers several potential benefits: it gives additional resources to produce the VSB and will make market penetration faster. With proper partnership with the correct firm, the team can also use a name that is already trusted in the market that's being targeted. This also gives the team options of licensing, selling, or some combination of the two.

6. Finances

Formatted: Indent: Hanging: 0.5", Numbered + Level: 1 + Numbering Style: 1, 2, 3, … + Start at: 6 + Alignment: Left + Aligned at: 0.25" + Tab after: 0.5" + Indent at: 0.5", Tab stops: 0.25", List tab + 0.38", Left + Not at 0.5"

Formatted: No bullets or numbering, Tab stops: 0.38", Left

Formatted: Line spacing: single

Currently, the EPA is suggesting regulations that will force coal power plants to reduce their emissions by 30-90% in increments over several years. Though the technology of Virtual Sorbent Beds (VSB) is still in the development phase, it is assumed that in order to be competitive, it will be able to reduce mercury emissions efficiently by 90% for the typical coal plant. The Department of Energy estimates that the cost of the technology for mercury removal at the range of 90% efficiency will be $25,000 to $75,000 per pound, or $2.6 billion to $7.3 billion annually[3]. These figures consider the total cost for the industry to run the technology for a year. In the case of the VSB technology, this includes costs for the injection of activated carbon and the removal of the waste. Effects that the implementation of the technology will have on the plant, specifically the maximum levels at which plants can continue to run, need to be explored with additional time and resources. However, for the current level of analysis it is necessary to assume that these changes will be negligible. In order to be marketable to the coal plants, it will be necessary for the VSB technology to be operated at less than the projected $2.6 billion and for it to be installed at far less. Competing technologies are estimated at implementation rates of $500,000[4]. Until further research and development can yield more exact figures as to the cost of implementation, the figure of $500,000 will be used to analyze the different market strategies the VSB has available to it.

There are three major methods of implementing this technology that will be examined for the purpose of financials. While it is understood that combinations of these three could

[3] http://www.southernresearch.org/sri/pubs/enviro_energy/mercury_emissions.pdf

[4] http://groups.msn.com/AAEA/mercury1.msnw

Formatted: Right: 0.25"

Formatted: Right: 0.25"

also be beneficial, these options will be mapped out in order to better understand the borders of the different marketing strategies. Licensing describes entering the market through an intermediary, and charging them a rate based on income or units sold. In contrast to this, selling would involve a set amount, either upfront or spaced out over payments, that is independent of how well the intermediary does. Finally, the option of manufacturing discusses the ability of the current resources and team to enter the market itself, without an intermediary, allowing the VSB technology at the cost of additional resources, to capture the total profit margin of the end user market. To give the team a benchmark as to the technologies potential, licensing will be explored. From this, it is assumed that a selling price can be reached, and that the manufacturing options can be compared to this baseline.

Of the three options, licensing offers a balance between the risks taken and the total amount of income received. The additional risk of over-selling comes from the fact that the company is placing stakes on the amount of units sold, a factor not guaranteed. The reduced income from manufacturing is due to the majority of the profit going to firms that install and directly sell the technology. The income the team would receive from licensing is based off of three important factors: number of licensors, percentage amount, and what the percentage is based on (income, profits, units sold, etc). The last factor is decided based on the level of involvement the team wants to take after licensing the technology. For example, while choosing to base the royalties off of the profit made from each sale will yield in a higher total return, it would require the team to audit the books of all the companies that licensed the technology. Given the current state of the technology and the costs to the team to maintain an active watch on it, it is understood that the team would likely prefer to base royalties off of income. It is this assumption that the analysis is based upon.

The number of licensees affects income in several ways. First, it allows for multiple streams of income; by licensing to several architectural engineering firms, there are several groups that would be selling the product. While in the long run this might end in the same number of units sold, it transitions into the other effect of quicker market penetration. Lastly, by not offering exclusive rights to one firm, the percentage that can be charged is capped. The percentage that is charged is the main factor for figuring out exactly how much the option of licensing would be worth. Based upon an interview, these percentages were estimated to be in the range of 5-10%, fluctuating based on several factors[5]. Considering the current level of technology and the option to license to several firms at once, a royalties amount of 5% will serve as a base, with the understanding that several factors can be adjusted to increase or decrease this amount. The changes include, but aren't limited to:

- Increased R&D
- Exclusive rights
- Additional support

Formatted: Bullets and Numbering

The attached graphs represent a collection of gradual estimations. First, the market penetration was estimated. This was done using the standard logarithmic model

[5] Interview Dr. Gottlieb

Formatted: Right: 0.25"

with the assumption that there will be peaks in the demand around the years where the regulations are phased in. These represent a market penetration that starts immediately, but only captures 50% of the market. To compare the different values to an equivalent investment, the data is regressed to a present day value. This value is based on the stock market's average annual return for a 75 year span, and this return on investment was 11%.[6] The percentages of 2%, 3%, and 5% are based on interviews throughout the semester with different people that are well versed in the area of intellectual property. They are just estimation and further research and information would be necessary.

In order to bring the technology to the market without an intermediary, several additional resources would be required. First and foremost, the research and development must be completed on the technology itself. This would require a large amount of funding in order to test the technology on the scale that it needs to be proven at. After the technology is completely designed and is fully proven, a plant or firm would need to be developed in order to produce the devices that are going to be installed. To sell to enough plant to prove profitable, the manufacturing of the product will need to be structured for a large scale operation. This also takes a lot of resources and time to set in place. In addition to these things, the company would need to create market awareness and worry about penetrating the market of coal plants, which could prove to be difficult in such an old and set market. All of these items add together to represent a task that seems to require a large amount of resources for an insufficient return. Though manufacturing the technology ourselves would allow the team to capitalize directly on the final market, the resources and time to market that this option would take make it a very unattractive proposition. Though considered as an option it is seen as something that has so limited of returns as to not warrant further investigation of the alternative.

7. Risks

7.1 Overview in Risks

In the process of developing the business plan for VSB, we realized that there are many risks involved that we need to consider before we can successfully develop the business plan. These risks will enable us to understand all the affecting parameters of this business plan. Some of these risks may be crucial in deciding the fate of this business plan, whether it will be successful or complete failure.

7.2 VSB Technology Risks

7.2.1 Theoretically Sound Concept, But Limited Experimental Data

VSB has been developed as a theoretically sound concept; however, due to the fact that the technology is still in its early researching and development phase, there has been limited experimental data. Most of our data are based on how it could work conceptually, not in the real industry.

At this point, Dr. Clack has only built a prototype model of a VSB. There is no full-scale

[6] http://www.finfacts.com/stockperf.htm

Formatted: Right: 0.25"

Formatted: No bullets or numbering, Tab stops: 0.38", Left

Formatted: Indent: Hanging: 0.5", Numbered + Level: 1 + Numbering Style: 1, 2, 3, … + Start at: 6 + Alignment: Left + Aligned at: 0.25" + Tab after: 0.5" + Indent at: 0.5", Tab stops: 0.25", List tab + 0.38", Left + Not at 0.5"

Formatted: No bullets or numbering, Tab stops: 0.38", Left

Formatted: Font: Not Italic, Font color: Black

Formatted: Font: Bold, Not Italic, Font color: Black

Formatted: Font: Not Italic, Font color: Black

Formatted: Font color: Black

Formatted: Right: 0.25"

VSB in existence so far. In addition, the prototype has only been used to test the control of the activated carbon path. It has not been tested for mercury removal.

7.2.2 Unknown VSB Efficiency

Theoretically, the VSB should remove a high percentage of the mercury in the gas stream, but there have been no tests done to prove this. Therefore, it is unknown what the efficiency of the VSB is. The fact that the efficiency is unknown is a huge risk. It means that the technology is not guaranteed to meet the regulations. Although it theoretically should, this is not yet proven.

7.2.3 Unconfirmed Costs Associated with VSB

Also, because the efficiency is unknown, it is impossible to accurately cost the VSB. Efficiency in activated carbon based technologies is dependant on the size and amount of activated carbon used. The smaller, more efficient carbon costs more to buy, and obviously more activated carbon costs more to buy. Also, the activated carbon needs to be stored in some manner at the power plant. Since the amount of carbon needed is unknown, it is impossible to accurately determine the size of tower needed to store the carbon. This means that in addition to not knowing the operating cost for the carbon, the construction cost for the tower and delivery system for putting the carbon into the VSB is not accurately known.

7.2.4 Unknown VSB's Full-Scale Dimensions and Space Requirement

Another problem with having the VSB technology still in the developmental stage is there is no way to determine the full-scale size of a VSB. Theoretically, the VSB should fit either inside or on the end of existing ESPs, but this has yet to be proven. Should the VSB need to be bigger than the ESPs, there may be problems in fitting the VSB into the power plants. The power plants and ESPs were not designed to have space for mercury removal technologies and if the VSB is too big, they will not be able to use it.

7.2.5 Developing in time for market demand

The other problem with having the VSB still in the developmental stages is the timeline needed to successfully enter the market. If the technology experiences delays in development, it may not be ready for market when the second round of regulations come into effect. Should this happen, the market will disappear and all the money and effort placed into the development of the technology will be lost.

7.2.6 Effects on Other Equipments' Operations

Another technological problem may occur due to the fact that the VSB has not been tested in a full scale power plant. It is unknown what effect, if any, installing a VSB will have on the rest of the plant. Although theoretically it should be safe to install, there is a chance that installing the VSB could cause some other piece of equipment to fail. The most likely failure would occur in the ESP. Most ESPs are designed to run at or near their maximum capacity. Installing the VSB could cause the ESPs to fail to meet the particulate control regulations. This is just one potential failure that could possibly occur due to the addition of the VSB. A full scale test is needed to prove this will not occur.

7.2.7 Operational Safety Unknown

Formatted: Right: 0.25"

Formatted: Font: Bold, Not Italic, Font color: Black

Formatted: Font color: Black

Formatted: Font: Bold, Not Italic, Font color: Black

Formatted: Font color: Black

Formatted: Font: Bold, Not Italic, Font color: Black

Formatted: Font color: Black

Formatted: Font: Bold, Not Italic, Font color: Black

Formatted: Font color: Black

Formatted: Font: Bold, Not Italic, Font color: Black

Formatted: Font color: Black

Formatted: Font: Bold, Not Italic, Font color: Black

Formatted: Right: 0.25"

Also due to the lack of full scale testing, there is a lack of information regarding the safety of the VSB. The prototype is currently safe, but this is no guarantee that the full scale model will be safe. The VSB needs to be tested for these concerns as well. If the VSB should show a tendency to explode from the activated carbon sparking or if other safety issues crop up during testing, this would adversely affect the sales of the VSB technology. Once again, this theoretically should not happen but it has yet to be proven with testing.

7.3 Marketing Risks

7.3.1 Marketing Based on Concept

The VSB faces several challenges in reaching the market. One of these challenges is that the technology is currently unproven. Until the technology has been proven with extensive testing, no customer would be willing to buy the technology. There has to be physical proof that the VSB will work according to design.

7.3.2 Entering the Market Late

In addition to needing proving, the VSB is being developed at a relatively late date. Most of the competing technologies have been under development for several years and have already been tested. As such, they are considered much more reliable than the VSB technology. Also, their head start has allowed them to develop a market name for themselves. The power companies have had time to explore the advantages of these technologies and to do their own evaluations of the technologies. This disadvantage will need to be overcome in bringing the VSB technology to market.

7.3.3 Small Market Size

Related to the difficulties in starting late is the small size of the market. In order to have a successful business, the VSB will need to be sold to a large percentage of the available market. A large number of sales are needed to offset the cost of developing the technology. The small market size problem is exasperated by the late start in developing the VSB technology. The competition has had time to start claiming some of the market. With the small market size, losing even some of the market makes it more difficult to have a successful business.

7.4 Economic Risks

7.4.1 Waste Management

Another risk is that the power plants will not be able to safely dispose of the mercury-contaminated activated carbon in an economically responsible fashion. Mercury is a toxic substance that needs to be handled with care. This means that the contaminated carbon needs to be disposed of in a manner that does not endanger the workers or the public. VSB technology focuses more on how to remove Hg effectively, but not managing the mercury by-product/waste after it is removed from the power plant's system. The cost of this disposal could raise the cost of the VSB higher than that of some of the competing technologies.

7.4.2 Continuing Funding

Since the VSB technology is still in development, there is the risk that the development will fail. This could occur for one of many reasons, including lack of funding, technical

Formatted: Right: 0.25"
Formatted: Font color: Black
Formatted: Font: Bold, Not Italic, Font color: Black
Formatted: Font color: Black
Formatted: Font: Bold, Not Italic, Font color: Black
Formatted: Font color: Black
Formatted: Font: Bold, Not Italic, Font color: Black
Formatted: Font color: Black
Formatted: Font: Bold, Not Italic, Font color: Black
Formatted: Font color: Black
Formatted: Font: Bold, Not Italic, Font color: Black
Formatted: Right: 0.25"

failures and failure to get a patent. Any of these reasons could cause the technology to fail to reach the market. Should this happen, all of the effort and money put into developing the technology would be wasted.

However, VSB development so far has been pointing in the right direction.

8. Assumptions

8.1 Overview in Assumptions

Development of a business plan for Virtual Sorbent Beds Technology is limited in terms of resources and abilities. For instance, there is not enough financial data to allow the Enpro team to project a rough cost estimate of VSB installation cost. Hence, it is necessary to clearly state the underlining assumptions from which this business plan will rely and build upon. These assumptions are crucial by allowing the Enpro team to continue developing a business plan without all the required information available. These assumptions mainly relate to regulatory, technological and economical aspects.

As more resources and development are available, these assumptions may be proved false or unsubstantiated or may need revision. However, it is critical that these assumptions be made in order to speed up the business plan development.

8.2 Regulatory Assumptions

8.2.2 Power Plant Will Respond to Regulation

Unquestionably, both federal and state regulations are the main forces that stimulate a new market segment in pollution control market, specifically mercury control technology.

The degree of regulatory stringency will dictate the complexity and competitiveness of this pollution control market segment. The higher the mercury pollutant emission restriction, the more power plants and other research entities are willing to invest and develop the mercury control technology. Hence, they will respond to mercury regulation, otherwise they will be severely fined.

8.2.3Regulatory Stringency Determines Where the Market Is More Attractive

Based on the regulatory assumption above, VSB market is highly dependent upon how regulation develops across the country. Where there are discrepancies among federal and state regulations, VSB will more likely to compete in a more stringent regulatory driven market. For instance, the federal regulation aims to reduce mercury pollution from coal-fired power plant by 70% by 2018. However, the northeastern states - including Maine, New York, and others - intend to put a cap of 90%. As a result, VSB will be actively marketed in these northern states as compared to other states.

8.3 Technological Assumptions

8.3.1 VSB has High Efficiency

Although there is no proven data to show VSB's efficiency, it is assumed theoretically to have higher efficiency than currently accepted activated carbon based technologies. Since current activated carbon technologies range in mercury removal efficiency from 60% to 90%, VSB will have an efficiency from at least 70%-98%. This assumed efficiency will

Formatted: Right: 0.25"
Formatted: Font: Bold
Formatted: Font color: Black
Formatted: Font: Bold, Not Italic, Font color: Black
Formatted: Font color: Black
Formatted: Font: Bold, Not Italic, Font color: Black
Formatted: Font color: Black
Formatted: Font: Bold, Not Italic, Font color: Black
Formatted: Font color: Black
Formatted: Right: 0.25"

put VSB in the top mercury control competing technological category and, consequently, able to meet and surpass at least the federal regulations.

8.3.2 VSB Must Compete With Other Technologies
VSB is not the only technology currently in development in the area of mercury control technologies. To penetrate the mercury pollutant technology market, VSB must compete with other technologies and prove its efficacy.

VSB's efficacy (in both efficiency and cost) will make VSB a viable solution among other competitive mercury control technologies, including MerCAP™, Amended Silicates™, and others.

8.3.3 VSB Will Development in Time to Meet Market Demand
In order for VSB to gain a share of the pollutant control market, it is critical that VSB will be developed and tested thoroughly from bench-scale testing to full-scale testing. Estimated needed time for developing and testing a mercury control technology before commercialization is over a decade.

Hence, VSB's proofs-of-concept need to be provided before the end of the first federal regulatory phase in 2010 to show VSB's efficacy in meeting or surpassing the regulated emission limit.

8.3.4 VSB Will Not Affect Other Equipment's Operations
VSB will be added as a separate module to current ESP technology. Its functions and operations will not interfere severely or handicap, if any, other equipments' operations.

8.4 Economic & Marketing Assumptions
8.4.1 Resource & Market Size Are Limited
On the economic perspective, we assume that the resource & market size for mercury control technology are both limited. There are a limited number of coal-fired power plants with ESP installed within the U.S. (about 400 coal-fired plants. Refer to the Market Size section for more details).

Coal-fired power plants have limited resources to invest and time to develop. Investment in a mercury control technology is very expensive. Once a power plant has decided and committed to a technology, it is very hard for us to convince or sell our VSB technology to them.

8.4.2 Primary Market Target Will Be Plants With ESP Installed
Because of the way VSB is compatible with ESP technology (about 70% of the total market), we assume that our primary VSB market target will be those power plants that have ESP installed. As VSB technology is widely accepted, other markets will be considered.

8.4.3 VSB Unit Price is $500,000

Formatted: Right: 0.25"
Formatted: Font: Bold, Not Italic, Font color: Black
Formatted: Font color: Black
Formatted: Font: Bold, Not Italic, Font color: Black
Formatted: Font color: Black
Formatted: Font: Bold, Not Italic, Font color: Black
Formatted: Font color: Black
Formatted: Font: Bold, Not Italic, Font color: Black
Formatted: Font color: Black
Formatted: Font: Bold, Not Italic, Font color: Black
Formatted: Font: Bold, Font color: Black
Formatted: Font color: Black
Formatted: Font: Bold, Not Italic, Font color: Black
Formatted: Right: 0.25"

For calculating purposes, VSB unit price is assumed to be $500,000. Until further research and development can yield more exact figures as to the cost of implementation, the figure of $500,000 will be used to analyze the different market strategies the VSB has available to it.

8.4.4 Highest Profit Decides the Market Strategy

Given the current state of the technology and the costs to the team to maintain an active watch on it, it is understood that the team would likely prefer to base royalties off of income. Hence, licensing VSB technology to manufacturing companies is the most feasible strategy.

8.4.5 Coal Will Continue to be Available and in Demand

Coal-fired power plants will continue to resort to coal because of its abundance and cheapness. Coal supply has been estimated to last at least another 400 years.

The essence of mercury pollutant problem is the emission of mercury from the coal that coal-fired power plants burn to convert to energy. Hence, it is crucial that coal will continue to be available and in high demand for VSB to be applicable in the decades to come.

Formatted: Right: 0.25"

Formatted: Font color: Black

Formatted: Font: Bold, Not Italic, Font color: Black

Formatted: Font color: Black

Formatted: Font: Bold, Not Italic, Font color: Black

Formatted: Font color: Black

Formatted: Right: 0.25"

Formatted: Right: 0.25"

Assignments

Formatted: Font: 14 pt

Finances: Byung, Matt, Mia
Strategy: Matt, Byung
Risks: Khiem, Chris
Regulations: Noel, Chris
Website: Khiem
Path Forward: Noel, Chris
Preparation for IPRO Day: Everyone

Obstacles

Formatted: Font: 14 pt

Formatted: Font: 14 pt

The main barrier facing the EnPro team is focused on the fact that the VSB is still in the developmental stages. Due to this, it is hard to make adequate estimations on a lot of key concepts; such as costs -running, implementation, etc-, effectiveness, competitive ability. This is complicated by the lack of standard in which other competitive technologies estimate their costs at. This will make financials and decision making very complicated for the team.

The other barrier lies in understanding the regulations, as they are written for lawyers and politicians. We will need to dig through all the documents to discover the parts that are relevant for us.

Conclusion

Formatted: Font: 14 pt, Bold

Formatted: Right: 0.25"

References

Environmental Protection Agency, *Revision of December 2000 Regulatory Finding on the Emissions of Hazardous Air Pollutants from Electric Utility Steam Generating Units and the Removal of Coal- and Oil-fired Electric Utility Steam Generating Units* http://www.epa.gov/air/mercuryrule/pdfs/camr_final_regfinding.pdf

Environmental Protection Agency, *Mercury Content and Selected Fuel Properties ofAs-fired Coals and Supplemental FuelsBurned in Coal-fired Electric Utility BoilersNationwide in 1999* http://www.epa.gov/ORD/NRMRL/pubs/600r01109/600R01109appA.pdf

Clack, H. *Virtual Sorbent Beds: Enabling Technology For Compact Biochemical Sensor Systems*

Clack, H. *Virtual Sorbent Beds: Electrostatically Enhanced In-Flight Adsorption of Mercury for Coal-Burning Electric Utilities*

Presentation by Ravi Ravi K. K. Srivastava, October 14-15, 2003, Nashville, TN at ICAC Forum '03: ICAC Forum '03: Multi-Pollutant Emission Controls & Strategies, visited March 12th 2005. www.icac.com/forum2003/Session6_Srivastava.pdf

Senior, Constance L. "Behavior of Mercury in Air Pollution Control Deviceson Coal-Fired Utility Boilers" Reaction Engineering International. Salt Lake City, Utah. 2001

Williams, Ben. Sargent & Lundy. Interview. April 28th 2005.

World Bank. Visited on April 20th, 2005. http://www.worldbank.org/html/fpd/em/power/EA/mitigatn/aqsowet.stm

Laudal, Dennis L. and Chad A. Wocken, "EVALUATION OF THE EFFECT OF SCR ON MERCURY SPECIATION AND EMISSIONS" University of North Dakota Energy & Environmental Research Center. Grand Forks, ND.

Foerter, David. "Attention Docket ID No. OAR-2002-0056." ICAC. July 29, 2004.

EERC. "Advanced Hybrid Filter." http://www.undeerc.org/commercialization/projects/hybrid.asp

Licata, Anthony. "Mercury Control for MWCs Using the Sodium tetrasulfide Process." Babcock Borsig Power, May 22, 2000.

Formatted: Right: 0.25"
Formatted: Font: 14 pt, Bold
Formatted: Font: 12 pt
Formatted: Font: 12 pt, Italic
Formatted: Font: 12 pt
Formatted: Hyperlink, Font: 12 pt
Formatted: Underline
Field Code Changed
Formatted: Font: Bold
Formatted: Font: 12 pt, Italic
Formatted: Font: 12 pt
Field Code Changed
Formatted: Hyperlink, Font: 12 pt, Font color: Auto
Formatted: Font: 12 pt, Bold
Formatted: Font: 12 pt
Formatted: Font: 12 pt, Italic
Formatted: Font: 12 pt
Formatted: Font: 12 pt, Bold
Formatted: Font: 12 pt
Formatted: Font: 12 pt, Italic
Formatted: Indent: Left: 0"
Formatted: Font: Bold
Formatted: Indent: Left: 0"
Formatted: Font: Bold
Formatted: Font: Bold
Formatted: Font: Bold
Formatted: Font: Bold
Formatted: Font: Bold
Formatted: Font: Bold
Formatted: Font: 12 pt
Formatted: Font: 12 pt, Underline
Formatted: Font color: Auto
Formatted: Right: 0.25"

Results to Date

In the first half of the IPRO, we worked on the following objectives:

- Market size
- Marketing strategy
- Competition

Results from Market Size

- The market will be driven by the new government regulations regarding mercury pollution from power plants
- There are 200 companies operating 422 coal-fired power plants
- In 2003 these companies spent $2 billion dollars on air pollution control
- The market is segmented by three different concerns: age, coal type and whether or not they have an electrostatic precipitator (ESP)
- Age is a concern because some of the plants may be grandfathered in and will not need to control mercury pollution. We are currently looking at the regulations to verify if this is a concern for us.
- The next major segmentation is whether or not the plant has an ESP. The VSB technology that Dr. Clack is developing is designed as an attachment to existing ESPs. As such, we are mainly interested in selling to plants with ESPs and plants that will be installing ESPs.
- The third segmentation is by coal type. The ideal type of coal is bituminous coal, as it is the most common type and it works well with technologies similar to the VSB. Another coal type we are interested in is sub-bituminous. All other coal types are being ignored for our research as they concern only a very small part of the market.
- Table 1 shows the results of these segmentations

Table 1

Total ESP at Coal-Fired Power Plants	**1122**	All generators' Years >= 1970	**299**	Cold-Side	229	Bituminous Coal	**152**
						Subbituminous Coal	59
						Other Coals	18
				Hot-Side	70	Bituminous Coal	45
						Subbituminous Coal	25
						Other Coals	0

Formatted: Right: 0.25"

Formatted: Font color: Black

Formatted: Bullets and Numbering

Formatted: Bullets and Numbering

Formatted: Right: 0.25"

Formatted: Right: 0.25"

		Some generators' Years >= 1970	**292**	Cold-Side	221	Bituminous Coal	**172**
						Subbituminous Coal	47
						Other Coals	2
				Hot-Side	71	Bituminous Coal	58
						Subbituminous Coal	13
						Other Coals	**0**
		All generators' Years<1970	**531**				

Results from Marketing Strategy

Formatted: Bullets and Numbering

- We examined three different marketing strategies: Selling, licensing and manufacturing
- Selling would entail selling all rights to the VSB, intellectual and otherwise. These rights would be sold to an intermediary who would then continue developing the VSB and manufacturing it. We would be paid a set amount that is not linked to the amount of VSBs sold. Most of the profit would go to the intermediary, but the risk to us would be smaller.
- With licensing, we would retain intellectual rights to the technology. We would sell the right to produce the VSBs to intermediaries. We would then get paid a percentage of the sales of each VSB unit. This option contains more risks as we are paid per VSB, but we may get more profit in return. We could license out exclusive rights or not, depending on what % of sales would give us better options
- The third option is for us to manufacture the product ourselves. This would entail setting up a factory to produce it, hiring people to make it and other expenses. This option contains large risks, because all the risks and expenses are incurred by us, instead of being shared with an intermediary. The advantage is that we would not have to share the end profits with the intermediary. This option requires large amounts of capital and time to set up and we feel that it is not worth the risks involved.

Competition results

Formatted: Bullets and Numbering

- In analyzing the competition, we looked at various other technologies that are trying to break into this market. We used a 70% efficiency cut-off to determine whether or not the opposing technology would be effective. We did this work prior to the publishing of the new laws concerning mercury removal. Once we understand what the new regulations are, we will go back and adjust this list accordingly. We examined the following technologies as competition:

Formatted: Right: 0.25"

Formatted: Right: 0.25"

Hot-side ESP (H-ESP), Cold-side ESP (C-ESP), Fabric filter (FF), Spray-Dryers Absorbers(SDA) + FF, Flue gas desulphurization (FGD) + C-ESP, FGD+H-ESP, FGD + Wet Scrubber, Selective Catalytic Reduction (SCR), MerCap, Advanced Hybrid Filter, ECO Powerspan and various sorbent injection technologies.

- Out of these technologies, the following met the 70% cut-off:

    FF, H-ESP+FF, C-ESP+FF,SDA+FF, MerCap, Advanced Hybrid Filter, ECO powerspan,

- The SCR technology and the sorbent injection technologies can be used in conjunction with our technology and so were not considered actual competition.
- The ESP + FF designs are eliminated from the list of competitors as they are much more expensive than the other options
- The MerCap, Advanced Hybrid Filter and ECO powerspan technologies are still under development but they will provide us with competition, provided they meet EPA approval.
- That leaves our list of competing technologies at:

    FF, FF+SDA, Mercap, Advanced Hybrid filter and ECO powerspan.

- It is still necessary to do an in-depth cost analysis of these technologies.

Formatted: Bullets and Numbering

Formatted: Bullets and Numbering

Formatted: Bullets and Numbering

Formatted: Bullets and Numbering

Schedule for the remainder of the project

- We will be working on the following topics for the remainder of the semester.
- Finances, Risks, Regulations and Path-Forward
- All reports on these issues will be due by April 14th.
- The work is being divided into different sub-groups, with all reports due by then
- The remainder of the semester will be spent on polishing up the reports, developing the web page and preparing the IPRO day presentation.

Formatted: Bullets and Numbering

Individual Assignments

Finances: Kim, Matt, Mia
Risks: Khiem
Regulations: Noel, Chris
Website: Khiem
Path Forward: Noel, Chris
Preparation for IPRO Day: Everyone

Barriers and Obstacles

- The main barrier facing the EnPro team is focused on the fact that the VSB is still in the developmental stages. Due to this, it is hard to make adequate estimations on a lot of key concepts; such as costs -running, implementation, etc-, effectiveness, competitive ability. This is complicated by the lack of standard in which other competitive technologies estimate their costs at. This will make financials and decision making very complicated for the team.

Formatted: Right: 0.25"

Formatted: Right: 0.25"

The other barrier lies in understanding the regulations, as they are written for lawyers and politicians. We will need to dig through all the documents to discover the parts that are relevant for us.**Exhibit 1** Revenue of Electricity Generation Business in 2000[7]

Item	**Type of Regulated Electric Utility**				
	Investor-Owned	**Publicly Owned**	**Cooperative**	**Federal**	**Total**
Number of Electric Utilities	240	2,009	894	9	3,152
Electric Utilities (percent)	7.6	63.7	28.4	.3	100.0
Revenues from Sales to Ultimate Consumers (thousand dollars)	169,444,470	33,054,956	20,506,101	1,242,031	**224,247,558**
Revenues from Sales to Ultimate Consumers (percent)	75.6	14.7	9.1	.6	100.0
Sales of Electricity to Ultimate Consumers (thousand megawatthours)	2,437,982	516,681	305,856	49,094	3,309,613
Sales of Electricity to Ultimate Consumers (percent)	73.7	15.6	9.2	1.5	100.0
Average Revenue per kWh for Ultimate Consumers (cents)	6.9	6.4	6.7	2.5	6.8
Revenues from Sales for Resale (thousand dollars)	35,359,346	13,430,253	12,027,771	8,900,091	**69,717,461**
Revenues from Sales for Resale (percent)	50.7	19.3	17.3	12.8	100.0
Sales of Electricity Available for Resale (thousand megawatthours)	854,228	301,412	311,935	248,664	1,716,239
Sales of Electricity Available for Resale (percent)	49.8	17.6	18.2	14.5	100.0
Average Revenue per kWh for Sales for Resale (cents)	4.1	4.5	3.9	3.6	4.1

[7] Source: Energy Information Administration, Form EIA-861, "Annual Electric Utility Report." Data are based on calendar year submissions.

Formatted: Right: 0.25"

Exhibit 2 Existing Capacity by Energy Source, 2003[8]

Energy Source (Megawatts)	**Number of Generators**	**Generator Nameplate Capacity (MW)**	**Net Summer Capacity (MW)**	**Net Winter Capacity (MW)**
Coal	1,535	**335,793**	**313,019**	**315,237**
Petroleum	3,121	40,965	36,429	40,023
Natural Gas	3,069	238,967	208,447	224,366
Dual Fired	3,056	190,739	171,295	183,033
Other Gases	105	2,284	1,994	1,984
Nuclear	104	105,415	99,209	100,893
Hydroelectric	4,145	96,352	99,216	98,399
Other Renewables	1,582	20,474	18,199	18,524
Other	39	704	638	640
Total	**16,756**	**1,031,692**	**948,446**	**983,099**

Exhibit 3 Estimated Revenue Generated by Coal-fired Plants

2000 Revenue: Electricity Generation (thousand dollars)	Revenues from Sales to Ultimate Consumers	224,247,558
	Revenues from Sales for Resale (thousand dollars)	69,717,461
	Total Revenue (thousand dollars)	**293,965,019**
Capacity Percentage: Coal-Fired Power Plants (Megawatts)	Total Capacity from Coal-Fired Plants	964,049
	Total Capacity from all sources	2,963,237
	Capacity Percentage: Coal	**32.53%**
Estimated Revenue Generated by Coal-Fired Power Plants (thousand dollars)	Total Revenue (thousand dollars) X Capacity Percentage	**95,626,821**

[8] Source: Energy Information Administration, Form EIA-860, "Annual Electric Generator Report"

Formatted: Right: 0.25"

Formatted: Right: 0.25"

Formatted: Right: 0.25"

Exhibit 4 Quick Facts for Coal-Fired Power Plants

Number of Companies	**200**	
Number of Plants	**422**	
Capacity (Megawatts)	Nameplate	335,793
	Summer	313,019
	Winter	315,237
	Total	**964,049**
Capacity Percentage: Coal-Fired Power Plants (Megawatts)	Total Capacity from Coal-Fired Plants	964,049
	Total Capacity from all sources	2,963,237
	Capacity Percentage: Coal	**32.53%**
Estimated Revenue Generated by Coal-Fired Power Plants (thousand dollars)	Total Revenue (thousand dollars) X Capacity Percentage	**95,626,821**

Exhibit 5: Schematics of Ordinary Electrostatic Precipitation (left) Compared to Virtual Sorbent Bed, top view (center) and end view (right).

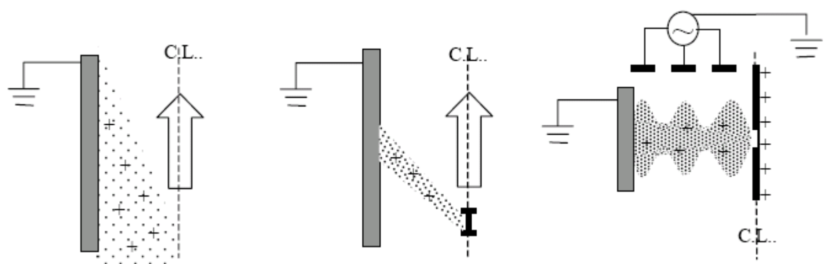


Exhibit 6 List of companies in the ESP industry (from The Institute of Clean Air Companies, an association of air pollution monitoring companies)

ALSTOM Power
Babcock & Wilcox
Belco Technologies Corporation
F.L. Smidth Airtech, Inc.
Marsulex Environmental Technologies
Solios Environment
Babcock Power Inc.
Wheelabrator Air Pollution Control
Hamon Research-Cottrell, Inc.
Forney Corporation
NWL Transformers

Formatted: Right: 0.25"

Exhibit 7 Financial Table

	Market Penetration - Annual								
	Year								
	1	3	5	10	13	15	20	Captured	Total
Plants	4.22	12.66	50.64	16.88	88.62	25.32	12.66	211	422
Percentage	0.01	0.03	0.12	0.04	0.21	0.06	0.03	50.00%	100.00%
	Market Penetration - Cummulative								
	Year								
	1	3	5	10	13	15	20	Captured	Total
Plants	4.22	16.88	67.52	84.4	173.02	198.34	211	211	422
Percentage	0.01	0.04	0.16	0.2	0.41	0.47	0.5	50.00%	100.00%

Formatted: Right: 0.25"

Formatted: Font: Bold

Formatted: Tab stops: 2.08", Left

Formatted: Right: 0.25"