DEMONSTRATION OF A FULL-SCALE RETROFIT OF THE ADVANCED HYBRID PARTICULATE COLLECTOR TECHNOLOGY

PUBLIC DESIGN REPORT
TOPICAL REPORT

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Prepared by:

Tom Hrdlicka
William Swanson
48450 144th Street
Big Stone Power Plant
Otter Tail Power Company

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Otter Tail Power Company
Big Stone Plant
PO Box 218
Big Stone City, SD 57216-0218

W.L. Gore & Associates, Inc.
101 Lewisville Road
Elkton, MD 21922-1100

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ABSTRACT

The Advanced Hybrid Particulate Collector (AHPC), developed in cooperation between W.L. Gore & Associates and the Energy & Environmental Research Center (EERC), is an innovative approach to removing particulates from power plant flue gas. The AHPC combines the elements of a traditional baghouse and electrostatic precipitator (ESP) into one device to achieve increased particulate collection efficiency. As part of the Power Plant Improvement Initiative (PPII), this project is being demonstrated under joint sponsorship from the U.S. Department of Energy and Otter Tail Power Company.

The project objective is to demonstrate the improved particulate collection efficiency obtained by a full-scale retrofit of the AHPC to an existing electrostatic precipitator. The full-scale retrofit will be conducted on an electric power plant burning Powder River Basin (PRB) coal, Otter Tail Power Company's Big Stone Plant, in Big Stone City, South Dakota. The $13.4 million project begins site preparation in July 2002 and particulate collection will commence in October 2002. Project related testing will conclude in November 2004.

The following Public Design Report has been prepared for the project entitled "Demonstration of a Full-Scale Retrofit of the Advanced Hybrid Particulate Collector Technology" as described in DOE Award No. DE-FC26-02NT41420. The report presents a description of the technology and design criteria for the demonstration as well as cost data for the design and construction of the AHPC. The influence of site-specific conditions on the design and economics of the technology are also discussed.

POINT OF CONTACT

For further information on the "Demonstration of a Full-Scale Retrofit of the Advanced Hybrid Particulate Collector Technology", please contact:

William Swanson
Otter Tail Power Company
Big Stone Plant
PO Box 218
Big Stone City, SD 57216-0218

TABLE OF CONTENTS

List of Figures

List of Tables

LIST OF ACRONYMS

AHPC	Advanced Hybrid Particulate Collector
CAAA	Clean Air Act Admendments
CFD	Computational Fluid Dynamic
COHPAC	compact hybrid particulate collector
CPC	condensation particle counter
DOE	U.S. Department of Energy
EERC	Energy & Environ. Research Center
EPA	U.S. Environmental Protection Agency
ePTFE	expanded polytetrafluoroethylene
ESP	electrostatic precipitator
EVMS	Earned value management system
FF	fabric filter
HEPA	high-efficiency particulate air
HiPPS	high-performance power system
kacfm	thousand actual cubic feet per minute
kV DC	thousand volts direct current
kW	thousand Watts
MACT	Max Achievable Control Technology
MWh	megawatt hours
NAAQS	National Ambient Air Quality Standards
NESHAPs	National Emission Standards for Hazardous Air Pollutants
NPDES	National Pollutant Discharge Elimination System
NSPS	New Source Performance Standards
OEMs	Original equipment manufacturers
OTP	Otter Tail Power CompanyOE
PJBH	pulse-jet baghouse
PJFF	pulse-jet fabric filter
PM	particulate matter
PRB	Powder River Basin
PSD	Prevention of Significant Deterioration
QAPP	Quality assurance project plan
RGFF	reverse-gas fabric filter
SCA	specific collection area
SMPS	scanning mobility particle sizer
TR	transformer-rectifier
UND	University of North Dakota
V AC	volts - alternating current
W.C.	water column
WG	water gauge
µm	micrometer

EXECUTIVE SUMMARY

This document is meant as a summary of the design efforts of a project titled “Demonstration of a Full-Scale Retrofit of the Advanced Hybrid Particulate Collector Technology”. This project was awarded under a program entitled the Power Plant Improvement Initiative by the Department of Energy’s National Energy Technology Laboratory.

The Advanced Hybrid Particulate Collector (AHPC) was developed under funding from the U.S. Department of Energy (DOE). The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in an entirely novel manner. The AHPC concept combines fabric filtration and electrostatic precipitation in the same housing, providing major synergism between the two methods, both in the particulate collection step and in transfer of dust to the hopper. The AHPC provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emissions with conventional ESPs, and solves the problem of reentrainment and re-collection of dust in conventional baghouses.

A slipstream AHPC (9000 scfm) was operated at the Big Stone Power Plant for 1½ years. The AHPC demonstrated ultrahigh particulate collection efficiency for submicron particles and total particulate mass. Collection efficiency was proven to exceed 99.99% by one to two orders of magnitude over the entire range of particles from 0.01 to 50 µm. This level of control would be well below any current particulate emission standards. These results were achieved while operating at significantly higher air-to-cloth ratios (12 ft/min compared to 4 ft/min) than what is used for standard pulse-jet baghouses. For meeting a possible stricter fine-particle standard or 99.99% control of total particulate, the AHPC is the economic choice over either ESPs or baghouses by a wide margin.

Therefore, Otter Tail Power Company and its partners, Montana-Dakota Utilities and NorthWestern Public Service, are installing the AHPC technology into an existing ESP structure at the Big Stone Power Plant. The overall goal of the project is to demonstrate the AHPC concept in a full-scale application. Specific objectives are to demonstrate 99.99% collection of all particles larger than 0.01µm, low pressure drop, overall reliability of the technology and, eventually, long-term bag life.

PROJECT NOMENCLATURE DISCUSSION

When this technology was originally developed, the device was referred to as the "Advanced Hybrid Particulate Collector". Since the original development, from concept to an attempt at a commercial demonstration, the name of the technology has changed to "Advanced Hybrid™". This name was trademarked by W.L. Gore and Associates, Inc. to aid in the commercialization effort and tries to maintain the continuity of the successful history to date. Either "Advanced Hybrid Particulate Collector" (AHPC) or "Advanced Hybrid™" refers to the same process and or equipment.

1.0 INTRODUCTION

1.1 The Power Plant Improvement Initiative

On October 11, 2000, the Power Plant Improvement Initiative (PPII) was established under Public Law 106-291 "…for the commercial scale demonstration of technologies to assure the reliability of the Nation's energy supply from existing and new electric generating facilities…." The conference report provided as further guidance that the Power Plant Improvement Initiative "will demonstrate advanced coal-based technologies applicable to existing and new power plants…. The managers expect that there will be at least a 50 percent industry cost share for each of these projects and that the program will focus on technology that can be commercialized over the next few years. Such demonstrations must advance the efficiency, environmental controls or cost-competitiveness of coal-fired capacity well beyond that which is in operation now or has been operated to date."

According to the conference report, the law seeks to address concerns about electric power reliability, which might be measured through "increases in performance factors, such as efficiency, cost-competitiveness, and/or emissions removal required for both existing and new facilities." To fund the Power Plant Improvement Initiative, nominally $95 million in previously appropriated funds were transferred from the Clean Coal Technology (CCT) demonstration program. Public Law 106-291 also expanded repayment provisions to include foreign, as well as domestic, sales and licensing. Repayments are to be retained for future projects. Lastly, any project approved under the Power Plant Improvement Initiative shall be considered a Clean Coal Technology demonstration project under various federal regulations, such as new source environmental reviews.

The PPII is a follow-on to the Clean Coal Technology (CCT) demonstration program that was implemented successfully in the 1980s and 1990s. It uses funds that were first appropriated under the CCT program. Common features include commercial-scale demonstrations of advanced coal-based technologies, a minimum 50% industry cost share, repayment and other administrative provisions.

1.2 Purpose of the Public Design Report

The purpose of this Public Design Report is to provide non-proprietary design information for the Advanced Hybrid Particulate Collector Technology.

1.3 Technology Overview

The goal in developing a new approach for particulate control is to achieve as high a level of control as is practically possible, while at the same time providing high reliability, smaller size, and economic benefits. For dusts that are primarily larger than 20 µm, inertial separation methods, such as cyclones, are reasonably effective and are much more economical than conventional ESPs or baghouses. However, fine particles smaller than 2.5 µm pass through cyclones with little or no collection. If emission of even a small amount of fine dust is unacceptable, then cyclones are not a viable control method, and only ESPs and baghouses are capable of achieving any reasonable level of control. For these particles, the collection efficiency of a cyclone is close to zero; the efficiency of a modern ESP could approach about 99%; and the efficiency of a well-designed FF would be about 99.9%. Higher levels of control might be possible with an ESP, but only by a significant increase in the size or specific collection area (SCA). Since the goal for the AHPC is to be smaller and more economical than conventional approaches, achieving better fine-particle collection with electrostatic collection alone does not appear to be viable.

While theoretically possible, FFs cannot routinely achieve 99.9% fine-particle collection efficiency for all coals within economic constraints, and studies have shown that collection efficiency is likely to deteriorate significantly when the face velocity is increased. An approach to make FFs more economical is to employ smaller baghouses that operate at much higher air-to-cloth (A/C) ratios. The challenge is to increase the A/C ratio for economic benefits and to achieve ultrahigh collection efficiency at the same time. To achieve high collection efficiency, the pores in the filter media must be effectively bridged (assuming they are larger than the average particle size). With conventional fabrics at low A/C ratios, the residual dust cake serves as part of the collection medium, but at high A/C ratios, only a very light residual dust cake is acceptable, so the cake cannot be relied on to help achieve high collection efficiency. The solution is to employ a sophisticated fabric that can ensure ultrahigh collection efficiency and endure frequent high-energy cleaning. In addition, the fabric should be reliable under the most severe chemical environment likely to be encountered (such as the acidic conditions created by high SO_3 concentration). A fabric that meets these requirements is GORE-TEX® membrane on GORE-TEX® felt, which can achieve very high collection efficiencies at high A/C ratios. Although GORE-TEX® membrane filter medium is more expensive than conventional fabrics, the much smaller surface area required for the AHPC will improve the economics of using the GORE-TEX® membrane filter medium.

While very large ESPs are required to achieve >99% collection of the fine particles, a small ESP (SCA of less than 100 ft^2 of collection area/kacfm) can remove 90% to 95% of the dust including rapping puffs. In the AHPC concept, the goal is to employ only enough ESP plate area to remove approximately 90% of the dust and to minimize the cloth area by operating at an A/C ratio of least 12 ft/min. In a typical AHPC design, the ESP plate surface area and filtration surface are roughly equivalent. An AHPC operating at an

A/C ratio of 12 ft/min would require an SCA of 83 ft^2/kacfm. This is a factor of 6 times less fabric than a conventional baghouse operating at 2 ft/min and 6 times less plate area compared to a conventional ESP with an SCA of 500 ft^2/kacfm. Thus, the collection area of an ESP alone or a baghouse alone would be three times greater than the combined collection area in the AHPC.

The geometric configuration of the AHPC concept can be understood by comparing the configuration with a conventional pulse-jet baghouse (PJBH) where the individual bags or filtration tubes are 4–6 in. in diameter, 8–26 ft long, and mounted in and suspended from a tube sheet. The dust is collected on the outside of the bags while the flue gas passes through the fabric to the inside, then exits through the top of the bags into the clean air plenum and subsequently out of the stack. Cages are installed inside the bags to prevent them from collapsing during normal filtration. Air nozzles are installed above each bag to clean the bags with a quick burst of high-pressure air directed inside the bags. The burst of air, or cleaning pulse, causes a rapid expansion of the bag and momentarily reverses the direction of gas through the bag, which helps to clean the dust off of the bags. Typically, pulse-jet bags are oriented in a rectangular array spaced only a few inches apart. The bags are usually pulse-cleaned one row at a time in sequence, with 15 or more bags per row. Because of the narrow bag spacing and forward filtration through the two adjacent rows, much of the dust that is removed from one row of bags is simply re-collected on the adjacent bags. Only very large agglomerates of dust reach the hopper after pulsing. The phenomenon of redispersion and re-collection of dust after bag cleaning is one of the major obstacles to operation of baghouses at higher filtration velocity (A/C ratio).

Operation of the AHPC can be considered a two-step process. In Step 1, the particles are collected on either the grounded plates or the filtration surface, and in Step 2, the dust is transferred to the hopper. In Step 1, dirty gas flow enters the AHPC vessel and is directed into the ESP zone by appropriate baffling. The particles in the ESP zone immediately become charged and migrate toward the grounded plate at a velocity (electrical migration velocity) dependent upon the particle charge and electric field strength. For 10-µm particles, the actual migration velocity is approximately 2 ft/s or 10 times the filtration velocity of 12 ft/min (0.2 ft/s). This rapid movement of dust toward the grounded plate pulls some of the gas flow with it and, along with electric wind effects from the movement of charged gas molecules toward the plate, produces a "suction action" of the gas flow toward the plate. The gas cannot accumulate at the plate, so there is a resulting recirculation pattern produced by the combination of the forward entrance velocity parallel to the plate and the migration velocity perpendicular to the plate. Since all of the gas flow must eventually pass through the bags, a portion of the recirculation flow is drawn toward the bags. The greater migration velocities of particles moving toward the plates ensure that most of the particles will first be exposed to the

ESP zone and will collect on the plates before they have a chance to reach the filter. The particles that do reach the filtration surface will likely retain some charge. Charged particles are more readily collected because there is an additional coulombic force to drive the particles to a grounded or neutral surface. In addition, a dust cake formed from charged particles will be more porous, which produces a lower pressure drop. Ultrahigh fine-particle collection is achieved by removing over 90% of the dust before it reaches the fabric. Then using a GORE-TEX® membrane fabric to collect with a high efficiency the particles that reach the filtration surface.

In Step 2, the dust that accumulates on the grounded plates and filtration surfaces must be periodically removed and transferred from the bags and plates to the hopper. The bags are cleaned with a reverse pulse of pressurized air or gas with sufficient energy to dislodge most of the dust from the bags. A few larger agglomerates may fall directly to the hopper; however, much of the dust is reentrained into particles too small to fall directly to the hopper. While these are small particles, they are agglomerated into particles larger than those originally collected on the bags. In conventional baghouses, these particles would immediately be re-collected on the bags. In the AHPC, the unique method of bag cleaning and transfer of dust to the hopper prevents the re-collection of dust on the filter surface. The bags are pulsed with sufficient energy and volume to propel the reentrained dust past the high-voltage wires and back into the ESP zone, where they immediately become charged and are trapped on the plates. Since this reentrained cloud is composed of agglomerated particles larger than originally collected on the bags, they are trapped in the ESP zone much more easily than the original fine particles. The alternative rows of bags, wires, and plates act as an "electronic trap" to prevent the reentrained dust from being re-collected on the same bags, and the plates prevent the dust from being re-collected on adjacent rows of bags. This effect greatly reduces the accumulation of a residual dust cake and makes control of pressure drop at high A/C ratios much easier. The excess cleaning air passes into the hopper area and is eventually filtered by adjacent rows of bags. Since most of the dust collects on the grounded plates, these plates are rapped periodically, and the dust is released from the plates in large agglomerates that easily reach the hopper. Any fine dust that penetrates the ESP zone is collected at an ultrahigh efficiency by the bags. This completely eliminates any spike in emissions due to a rapping puff and makes redundant downstream fields completely unnecessary compared to conventional ESPs that require multiple fields to minimize rapping reentrainment. In the AHPC, there is major synergism between the ESP and filtration modes, each improving the operation of the other. The filter collects the excess ESP emissions during normal operation and during rapping, and the ESP collects the reentrained dust from the bags upon cleaning, which greatly enhances the ability to control pressure drop and operate at high A/C ratios. The AHPC is also superior to ESPs because it completely eliminates the problem of small amounts of dust and gas which bypass the electrostatic zone of the precipitator, because in the AHPC all of the flow must pass through the bags.

In addition to providing a high level of particulate control, the AHPC technology must do so in an economical manner. Assuming that the use of GORE-TEX® membrane filter media will achieve ultrahigh collection efficiency at high A/C ratios, the challenge is to control pressure drop. The following analysis shows that there is a good theoretical basis for operating FFs at much higher A/C ratios than typically employed.

For viscous flow, pressure drop across a FF is dependent on three components:

$$dP = K_f V + K_2 W_R V + K_2\, C_i\, V^2\, t / 7000 \qquad \text{[Eq. 1]}$$

where:

- dP = differential pressure across baghouse tube sheet (in. W.C.)
- K_f = fabric resistance coefficient (in. W.C.-min/ft)
- V = face velocity or A/C ratio (ft/min)
- K_2 = specific dust cake resistance coefficient (in. W.C.-ft-min/lb)
- W_R = residual dust cake weight (lb/ft^2)
- C_i = inlet dust loading (grains/acf)
- t = filtration time between bag cleaning (min)

The first term in Eq. 1 accounts for the pressure drop across the fabric. For conventional fabrics, the pore size is quite large, and the corresponding fabric permeability is high, so the pressure drop across the fabric alone is negligible. To achieve better collection efficiency, the pore size can be significantly reduced, without making fabric resistance a significant contributor to pressure drop. The GORE-TEX® membrane filter media allows for this optimization by providing a microfine pore structure while maintaining sufficient fabric permeability to permit operation at high A/C ratios. A measure of the new fabric permeability is the Frazier number which is the volume of gas that will pass through a square foot of fabric sample at a pressure drop of 0.5 in. W.C. The Frazier number of the bags for the Phase III tests is in the range from 4 to 8 ft/min. Through the filter, viscous (laminar) flow conditions exist, so the pressure drop varies directly with flow velocity. Assuming a new fabric Frazier number of 6 ft/min, the pressure drop across the fabric alone would be 1.0 in. W.C. at an A/C ratio (filtration velocity) of 12 ft/min.

The second term in Eq. 1 accounts for the pressure drop contribution from the permanent residual dust cake that exists on the surface of the fabric. For operation at high A/C ratios, the bag cleaning must be sufficient to maintain a very light residual dust cake and ensure that the pressure drop contribution from this term is reasonable. The contribution to pressure drop from this term is one of the most important indicators of longer-term bag cleanability, and is discussed further below.

The third term in Eq. 1 accounts for the pressure drop contribution from the dust accumulated on the bags since the last bag cleaning. K_2 is determined primarily by the fly ash particle-size distribution and the porosity of the dust cake. Typical K_2 values for a full dust loading of pulverized coal (pc)-fired fly ash range from about 4 to 20 in. W.C.-ft-min/lb but may, in extreme cases, cover a wider range.

Of interest is the maximum A/C ratio at which a baghouse can be expected to operate reliably for the range of K_2 values likely to be encountered. The third term dictates the minimum bag-cleaning interval. From Eq. 1, with a face velocity of 2.0 ft/min, a dust loading of 3.0 gr/acf, and a dP increase of 4 in. W.C., the required bag-cleaning frequency is greater than 100 min when K_2 is less than 23 in. W.C.-ft-min/lb. In a reverse-gas utility baghouse, cleaning takes place off-line and may require several minutes per compartment and more than an hour to clean all of the compartments. This is one reason why most reverse-gas baghouses are conservatively designed for a face velocity of 2 ft/min. To ensure that adequate cleaning time is available when K_2 is not known demands a conservative approach. On the other hand, if K_2 were known to be less than 7 in. W.C.-ft-min/lb, Eq. 1 implies that a face velocity of 4 ft/min could be employed. However, to date, reverse-gas baghouses have not been designed much above face velocities of 2 ft/min because an effective method of controlling K_2 has not existed and excessive residual dust cake weight is frequently encountered.

PJBHs have the potential to operate at much higher face velocities because bags can be cleaned more often and adequate pulse energy can usually prevent excessive residual dust cake buildup. Assuming that bag life is acceptable and that low particulate emissions can be maintained through the use of advanced filter materials, face velocities much greater than 4 ft/min should be possible. Assuming 10 minutes is the minimum cleaning cycle time for a PJBH, a face velocity of 4 ft/min is adequate to handle a dust with a K_2 greater than 72 in. W.C.-ft-min/lb. If K_2 is less than 14 in. W.C.-ft-min/lb, the face velocity can be increased to 8 ft/min. For many dusts, this might be possible with conventional systems. Doubling face velocity again to 16 ft/min implies that K_2 would have to be less than 4 in. W.C.-ft-min/lb. This is lower than most typical K_2 values; however, through the use of flue gas conditioning, it may be possible. Increasing the face velocity beyond 16 ft/min appears to be stretching the theoretical limit for a full dust loading of 3 gr/scf. However, if the actual dust loading that reached the fabric were reduced by a factor of 10, the allowable K_2 would increase by a factor of 10, while keeping the cleaning interval at 10 min. If a process could collect 90% of the dust before it reached the bags, a K_2 of up to 42 in. W.C.-ft-min/lb would be allowable at an A/C ratio of 16 ft/min and a 10-min bag-cleaning interval. The K_2 for almost all coal fly ash dusts is likely to be less than 42 in. W.C.-ft-min/lb, even allowing for some size fractionation between the precollected dust and the dust that reaches the bags. Therefore, a theoretical basis exists to operate a FF at a reduced dust loading and high A/C ratio with a reasonable bag-cleaning frequency.

The preceding analysis is valid as long as the dust can be effectively removed from the bags and transferred to the hopper without significant redispersion and re-collection. With pulse-jet cleaning, heavy residual dust cakes are not typically a problem because of the fairly high cleaning energy that can be employed. However, the high cleaning energy can lead to significant redispersion of the dust and subsequent re-collection on the bags. The combination of a very high-energy pulse and a very light dust cake tends to make the problem of redispersion much worse. The barrier that limits operation at high A/C ratios is not so much the dislodging of dust from the bags as it is transferring the dislodged dust to the hopper. Therefore, any improvement that facilitates transfer of the dislodged dust to the hopper without re-collection on the bags will greatly enhance operation at higher A/C ratios. The AHPC achieves enhanced bag cleaning by employing electrostatic effects to precollect a significant portion of the dust and to facilitate moving the dust from the bags to the hopper.

Bag-cleaning interval, t, is a key performance indicator. The goal is to operate with as long of a bag-cleaning interval as possible, since more frequent bag pulsing can lead to premature bag failure and requires more energy consumption from compressed air usage. For the AHPC, the design goal was to operate with a pulse interval of at least 10 min while operating at an A/C ratio of 12 ft/min.

Total tube sheet pressure drop is another key indicator of overall performance of the AHPC. Here, the AHPC goal is to operate with a tube sheet pressure drop of 8 in. W.C. at an A/C ratio of 12 ft/min.

To help analyze filter performance, the terms in Eq. 1 can be normalized to the more general case by dividing by velocity. The dP/V term is commonly referred to as drag or total tube sheet drag, D_T.

$$\frac{dP}{V} = D_T = K_f + K_2 W_R + \frac{K_2 C_i V t}{7000} \quad \text{[Eq. 2]}$$

The new fabric drag and the residual dust cake drag are typically combined into a single term called residual drag, D_R.

$$D_T = D_R + \frac{K_2 C_i V t}{7000} \qquad \text{[Eq. 3]}$$

The residual drag term then is the key indicator of how well the bags are cleaning over a range of A/C ratios, but may still be somewhat dependent on A/C ratio. For example, it may be more difficult to overcome a dP of 10 in. W.C. to clean the bags than cleaning at a dP of 5 in. W.C. For most baghouses, the residual drag typically climbs somewhat over time and must be monitored carefully to evaluate the longer-term performance.

Between bag cleanings, from the second term in Eq. 3, the drag increases linearly with K_2 (dust cake resistance coefficient), C_i (inlet dust concentration), V (filtration velocity), and t (filtration time). For conventional baghouses, the C_i term is easily determined from an inlet dust loading measurement, and approximate K_2 values can be determined from the literature or by direct measurement. However, for the AHPC, the concentration of the dust that reaches the bags is generally not known and would be very difficult to measure experimentally. From the Phase I laboratory tests, results indicated approximately 90% of the dust was precollected and did not reach the fabric. However, this amount is likely to fluctuate significantly with changes to the electrical field and with the dust resistivity. Since C_i is not known, for evaluation of AHPC performance, the terms K_2 and C_i can be considered together:

$$K_2 C_i = \frac{(D_T - D_R)\,7000}{Vt} \qquad \text{[Eq. 4]}$$

Evaluation of K_2C_i can help in assessing how well the ESP portion of the AHPC is functioning, especially by comparing with the K_2C_i during short test periods in which the ESP power is shut off.

Eq. 4 can be solved for the bag-cleaning interval, t, as shown in Eq. 5. It is clear that the bag-cleaning interval is inversely proportional to the face velocity, V, and the K_2C_i term and directly proportional to the change in drag before and after cleaning (delta drag). The delta drag term is dependent on the cleaning set point or maximum pressure drop as well as the residual drag. The face velocity, delta drag, and K_2C_i terms are relatively independent of each other and should all be considered when the bag-cleaning interval is evaluated. However, as mentioned above, the drag may be somewhat dependent on velocity if the dust does not clean off the bags as well at high velocity as at low velocity. Similarly, the K_2C_i term is somewhat dependent on velocity for a constant plate collection area. At the greater flow rates, the SCA of the precipitator is reduced, which will result in a greater dust concentration, C_i, reaching the bags.

$$t = \frac{(D_T - D_R)\ 7000}{VK_2C_i} \qquad \text{[Eq. 5]}$$

This analysis shows there is a strong theoretical basis for reasonable pressure drop and bag- cleaning interval with the AHPC.

1.4 Significance of Technology Commercialization and Process Advantages

Successful commercialization of the AHPC technology is dependent on two factors, potential future tightening of environmental regulations, and the fact that most coal-fired power plants rely on aging electrostatic precipitators (ESPs) for particulate control. Due to power plant switching from high sulfur coal to low sulfur (compliance) coal a significant number of these ESPs are operating on coal ash that is more difficult to capture and for which they were not designed. It will be important to the Big Stone Plant co-owners that the technology be widely commercialized so future operation and maintenance of the demonstration project is more cost effective.

The AHPC technology is a patented technology owned by the Energy & Environmental Research Center Foundation. W. L. Gore and Associates, has been granted an exclusive license to practice the technology for selected application including the utility industry, in selected countries worldwide, including the United States.

Gore does not engineer or construct the entire AHPC unit. Gore will depend on their ability to sublicense the engineering, manufacturing, and installation of the AHPC to original equipment manufacturers (OEMs).

The AHPC is capable of greater than 99.99% removal efficiencies. These numbers have been documented on a cyclone-fired boiler burning PRB coal. This application is probably the most challenging for particulate collection because of the overall finer-sized fly ash particles that are produced by a cyclone-fired boiler and the high dust resistivity of fly ash generated from PRB coals. The orders of magnitude improvement in PM capture provided by the AHPC can be realized in most retrofit opportunities in most coal-fired utility boilers at a lower capital cost and lower operating cost than other potential alternatives. The same holds true for new installations.

Comparing the AHPC to reverse-gas fabric filters (RGFFs) and pulse-jet fabric filters (PJFFs), which when sized conservatively typically achieve a removal efficiency of only 99.9%, the AHPC provides superior performance. FF particulate emissions are largely dependent on ash properties and typically increase if the A/C ratio is increased. In addition, conventional FFs may also have problems with bag cleanability and high-pressure drop, which has resulted in conservatively designed, large, costly baghouses. Also, many FFs cannot withstand the rigors of high-SO_3 flue gases, which are typical for bituminous fuels. The expanded membrane GORE-TEX® bags are much more acid resistant than conventional fabrics, so the AHPC can be employed in many bituminous coal applications where conventional FF would not be economical.

Comparing the AHPC to ESPs for a 500-MW plant, it is clear that many ESPs would have to be sized to 600–1000 SCA in order to even attain the present New Source Review Standard of 0.03 lb/MMBtu, representing only a 99.8% particulate removal efficiency. Another major limitation of ESPs is that the fractional penetration of 0.1- to 1.0-µm particles is at least an order of magnitude greater than for 10µm particles, so a situation exists where the particles that are of greatest health concern are collected with lowest efficiency. The AHPC has been shown in pilot-scale tests to remove even the finest particles at greater than 99.99%. In addition, the AHPC technology would also be applicable over a wider range of conditions than either ESPs or FF. It could be applied to both new installations and retrofits into an existing ESP housing. The compactness of its design allows it to be retrofitted into smaller ESP housings than other potential alternatives. For example, the RGFF technology is not a practical retrofit technology because it requires such a large footprint. The AHPC technology when sized at an A/C ratio of 12:1 requires a 22% smaller footprint than a conventional PJFF.

A competing innovative technology is the compact hybrid particulate collector (COHPAC). The original COHPAC is essentially a conventional ESP followed by a high A/C PJBH. Although the data are limited, full-scale demonstrations of COHPAC have reported similar efficiency numbers to RGFFs and PJFFs. This COHPAC technology has been modified to what is referred to as COHPAC II. In this scenario, one or more of the ESP fields are retrofitted with a PJBH operating at an A/C of 8.5 ft/min. The FF part of this technology would require less of a footprint than AHPC; however, when accounting for the space requirements for the ESP, the size is similar or larger than an AHPC unit operating at an A/C ratio of 12 ft/min.

Comparing the AHPC to existing particulate control technologies shows the following specific advantages:

- AHPC solves the problem of excessive fine-particle emissions that exists with conventional ESPs and eliminates the problem of sneakage.

- AHPC solves the problem of higher emissions from conventional baghouses when the A/C ratio is increased. This allows the AHPC to operate at very high A/C ratios, where conventional FF would be limited.

- AHPC solves the problem of reentrainment and re-collection of dust in conventional PJBHs caused by the close bag spacing and the effect of cleaning one row of bags at a time, which allows the AHPC to operate at very high A/C ratios, where conventional FFs would be limited.

- AHPC requires significantly less total collection area than conventional ESPs or baghouses.

- AHPC solves the bag problem of chemical attack that limits application of baghouses to low-sulfur coals by employing all ePTFE fabric when necessary.

- AHPC reduces the applicability problem for ESPs with high-resistivity dusts.

- AHPC is suitable for new installations, would be a good retrofit technology to replace existing particulate collectors, and would be an appropriate add-on retrofit technology such as placement after existing ESPs. This is a significant improvement over COHPAC, which is primarily a retrofit technology.

The purpose of the AHPC is to meet possible strict fine-particle control standards and achieve 99.99% particulate collection efficiency for all particle sizes from 0.01 to 50 µm. The AHPC overcomes the deficiencies of ESPs and FFs and achieves ultrahigh collection efficiency at a lower cost than competing technologies.

1.5 DOE's Role in the Project

The DOE is responsible for monitoring all aspects of the project and for granting or denying all approvals required by the Cooperative Agreement. The DOE Contracting Officer is DOE's authorized representative for all matters related to the Cooperative Agreement.

The DOE Contracting Officer appointed a Contracting Officer's Representative (COR) who is the authorized representative for all technical matters and has the authority to issue "technical advice" which may:

- Suggest redirection of the Cooperative Agreement effort, recommend a shifting of work emphasis between work areas or tasks, and suggest pursuit of certain lines of inquiry, which assist in accomplishing the Statement of Project Objectives.

- Approve those reports, plans, and items of technical information required to be delivered by the Participant to DOE under the Cooperative Agreement.

The DOE COR does not have the authority to issue any technical advice which:

- Constitutes an assignment of additional work outside the Statement of Project Objectives.

- In any manner cause an increase or decrease in the total estimated cost or the time required for performance of the Cooperative Agreement.

- Interferes with the Participant's right to perform the terms and conditions of the Cooperative Agreement.

1.6 Outreach Plan

The purpose of the outreach plan is to identify important milestones and information about the project and ensure timely identification of knowledge dissemination to the project partners and general public. The outreach activities will focus around the four major activities listed below.

1.6.1 Press Releases/Conferences of Important Milestones

There are four milestones that have been identified that would be candidates for public information dissemination.

1. Kickoff Announcement - 10/25/2002 (tentative)
2. Initiate Testing - 1/1/2003 (tentative)
3. AHPC Open House - 4/22/2003 (tentative)
4. Project Completion - 11/1/2004

The press release information listed above may be subject to change as the needs of the project dictate. During the course of the project, it may be necessary to add or delete certain items as agreed to by the key project personnel.

1.6.2 Web Page Information

The purpose of web page information will be to better explain the project to the public at large on a regular basis. The web site information would be held on the Otter Tail Power Company server. This information would be open for public viewing. As of the writing of this document, the specific web site information has not been developed.

1.6.3 Commercial Efforts

W.L. Gore and Associates is the sole license holder of this technology and as such will support the primary commercial outreach efforts. The following list is a description of the type of events that GORE is planning on attending to inform the industry and the public about the AHPC project:

1. Involvement in Press Release Information
2. Technology Exhibit – (8/11/2002), ESP/FF Roundtable, Dallas, TX
3. Paper Presentation – (9/9/2002), Air Quality III, Arlington, VA
4. Display Booth – (12/10/2002), PowerGen, Orlando, FL

1.6.4 Other Efforts

Additional efforts such as articles, papers, distribution of brochures, etc. may be pertinent for outreach activities. Some conferences that may be appropriate to attend are the Air and Waste Management Conferences, Particulate User's Groups, and Power Generation Conferences.

2.0 PROJECT OVERVIEW

2.1 Project History

This project is a result of the DOE Program Solicitation DE-PS26-01NT41104, Power Plant Improvement Initiative, and specifically addresses fine particulate control. The proposed work is a full-scale demonstration of the advanced hybrid particulate collector (AHPC). This demonstration will consist of retrofitting the AHPC into an existing ESP at the 450-MW Big Stone Power Plant. This proposal from Otter Tail Power

Company is a joint effort among Otter Tail Power, W.L. Gore & Associates, Inc. (Gore), ELEX AG, and the University of North Dakota (UND) Energy & Environmental Research Center (EERC).

In 1994, the EERC responded to the DOE Program Research and Development Announcement (PRDA) No. DE-RA22-94PC92291, Advanced Environmental Control Technologies for Coal-Based Power Systems Phases I and II, under Topic 7: Advanced Concepts for Control of Fine Particles and Vapor-Phase Toxic Emissions. The EERC proposal was subsequently selected for DOE funding, and the EERC was awarded Contract DE-AC22-95PC95258. Phase I work consisted of initial development of the AHPC starting as a completely new concept without any supporting experimental data. The project team included the EERC as the main contractor, Allied Environmental Technologies Company as a subcontractor, and Gore, as a technical and financial partner. Following highly successful results from the Phase I work, the EERC submitted a Phase II downselection proposal to DOE in June 1997 to continue development of the AHPC. The 2-year Phase II contract was awarded in March 1998 and included additional 200-acfm testing, similar to the tests completed in Phase I, as well as design, construction, and testing of a 9000-acfm (2.5-MW equivalent) version of the AHPC. The 9000-acfm slipstream AHPC was installed at the Big Stone Power Station, operated by Otter Tail Power Company. It was operated a total of 4.5 months as part of the Phase II award.

2.2 Project Objectives

The overall goal of the project is to demonstrate the AHPC at the full-scale level to meet current particulate emission standards and to demonstrate a superior fine-particle control technology that could meet any potential standards that may be imposed for fine particulate well into the 21st century. This goal has remained unchanged since the concept was originally proposed in 1994. The AHPC approach is to use filtration and electrostatic mechanisms in a unique manner that is superior to conventional fabric filters (FFs) and ESPs.

Specific objectives of the 3-year retrofit AHPC demonstration project at the Big Stone Power Plant are to:

- Demonstrate that the AHPC technology can be retrofitted into an existing ESP at the full-scale level.

- Demonstrate the ability of a retrofitted AHPC to meet performance specifications without derating the plant because of high opacity.

- Demonstrate the ability of the AHPC to provide >99.99% particulate collection efficiency for all particle sizes greater than 0.01 µm.

- Demonstrate the reliability of the AHPC as defined by maintenance requirements that are the same or less than standard ESPs or baghouses.

- Demonstrate the ability of the AHPC to achieve low pressure drop at an air-to-cloth (A/C) ratios of 10-12 ft/min.

- Demonstrate the long-term operability of the AHPC.

- Demonstrate the economic viability of the AHPC.

2.3 Project Organization

Overall project management will be provided by Otter Tail Power Company. Both Otter Tail Power and Gore will be providing cost share to the project. The project organizational chart is shown in Figure 1.

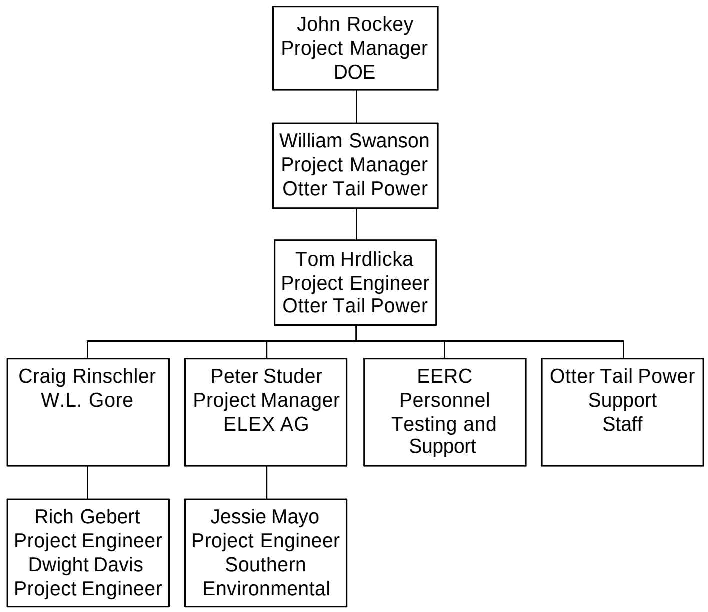

Figure 1 Project Organizational Chart

2.3.1 Otter Tail Power Company

Mr. William Swanson from Otter Tail Power Company will be the overall Project Manager. Otter Tail Power will be providing the site, financial commitment, and technical assistance to the project. As Project Manager, Mr. Swanson will be the overall team leader and will be responsible for overall technical direction of activities within the project. Specific responsibilities of the Project Manager will be to:

- Serve as the primary contact between DOE and the rest of the project team.
- Coordinate all project activities among DOE, Otter Tail, Gore, ELEX, and the EERC.
- Supervise the project team to ensure timely completion of project activities and ensure the work meets the highest technical standards.
- Ensure the design and installation of the AHPC meet all stated specifications.

- Review all data and report results to DOE and the entire project team.

- Ensure that contractual terms are met.

2.3.2 W.L. Gore & Associates, Inc.

The role of Gore in this project is as a technical and financial partner. All of the filter bags necessary to complete the proposed work will be provided by Gore along with technical guidance in support of this project. In addition to providing the bags, Gore will also develop and provide operational information designed to prove the technology. This will include pulling bags periodically from the AHPC and doing testing to evaluate performance and determine bag wear. Gore will have three key personnel as part of the project team: Mr. Craig Rinschler, Mr. Richard Gebert, and Mr. Dwight Davis. Mr. Rinschler will be the project manager for Gore, and Mr. Gebert and Mr. Davis will be project engineers.

Duties assumed by the Gore project team include the following:

- Organize commitments with partners

- Provide the necessary resources to meet the schedule, and review finalized designs

- Provide input into what the marketplace is looking for in this technology

- Act as the link between this technology demonstration and the marketplace

- Coordinate activities between ELEX, Otter Tail Power Company, and Gore

- Assist with start-up operations and training of Otter Tail personnel

- Evaluate the operation of the AHPC unit and the technology’s performance to determine when to officially launch the technology for commercialization

2.3.3 ELEX AG

ELEX will be a subcontractor to Otter Tail Power. ELEX will design and install the proposed AHPC. Mr. Peter Studer, will be the project manager for ELEX. Mr. Studer will oversee all aspects of the demolition of the current ESP, design of the AHPC, installation, and shakedown. Mr. Studer will be responsible for ensuring the AHPC meets the design specifications as outlined in the ELEX subcontract.

2.3.4 EERC

The EERC will serve as the testing team to verify the particulate removal efficiency results after the AHPC has been installed at the Big Stone Plant. The EERC has extensive experience in flue gas testing and the test plan is included in Table 5, Section 3.4.

2.4 Host Site

The Big Stone plant was commissioned for service in 1975. It consists of one 450-MW-rated, Babcock and Wilcox cyclone-fired boiler. All the flue gas passes through an ESP which consists of four chambers each having four fields. More than 70 Otter Tail Power Company employees operate and maintain the plant for the three owners.

The primary fuel for the first 20 years of operation was North Dakota lignite, but in 1995, the primary fuel was switched to PRB subbituminous coal. This fuel has approximately one-half of the moisture and one-third more heating value than North Dakota lignite. Almost all of the effects of this new fuel have been positive. However, one challenge that has occurred is a decrease in the particulate collection efficiency of the ESP because of an increase in resistivity of the fly ash. The combination of a very fine particle size produced from the cyclone-fired boiler and high ash resistivity has resulted in problems both in terms of meeting opacity requirements and in maintaining the ESP.

2.4.1 Site Assessment and Plan Development

As a brown-field site, assessment of the AHPC project area consists primarily of the overall size of the completed project, and the lay-down area necessary for construction.

Almost all of the completed project components will function inside the casing of the existing ESP. The overall footprint will be exactly the same. The only exterior differences will be the clean air plenums on top of each precipitator field, and the clean gas ducts from the plenums to the existing ID Fan suction duct. Special consideration will have to be given to the overhead area above the existing chamber 1A. There is an existing coal conveyor that is directly above this chamber. A completed design of the clean gas ductwork from this chamber, as well as crane access for construction in both that chamber and the adjacent chambers must take into account the limited overhead room. There is no anticipated problem at this time.

There is fairly substantial room in areas adjacent to the existing precipitator for laydown areas required during construction. The installation contractor will need to determine final locations for office, tools, equipment trailers, and component laydown areas, while making sure that access on critical plant roads remains open.

2.4.2 Selective Procurement

The longest lead-time items were identified so the critical path to complete material procurement would be met. These items were specific ELEX designed and supplied components. This required overseas shipment and a slightly longer lead time than if the components were built domestically.

The items identified with the longest lead time were the suspension bars that support the collecting electrodes and the collecting electrodes. The suspension bars were required for pre-fabrication of components before installation, so they were the longest lead time item. The order for the suspension bars needed to be placed by February 25, 2002 for an installation scheduled to begin September 16, 2002. This lead-time is approximately 30 weeks. Although this schedule may be improved on, procurement of materials was fast-paced and it appears to be a reasonable schedule.

2.5 Environmental Permit Applications

An application was submitted to the South Dakota Department of Environmental and Natural Resources (SDDENR) for a minor operating permit amendment. The application contained the following information:

1. A description of the pollution control project (including plans and specifications), the resulting change in emissions, and any new applicable requirement;
2. Any draft permit changes; and
3. Certification by a responsible official that the pollution control project meets the applicable requirements of a minor permit amendment.

The modifications made to the ESP in retrofitting the AHPC are exempt from the requirements of a major source modification as listed under 40 CFR Part 52.21 (b)(2)(iii)(h). Furthermore, the proposed project is also exempt under 40 CFR 52.21 (b)(32)(ii), which provides for a pollution control project major modification exemption to accommodate switching to a fuel that is less polluting. Big Stone Plant switched from burning lignite to subbituminous coal in 1995 to meet federal acid rain requirements.

2.6 Project Schedule

The project schedule is broken up into five main categories, which include Engineering, Purchase, Manufacture, Delivery, and Erection & Commissioning. Engineering began in December 2001, and the Erection and Commissioning concludes in November 2002. The disassembly of the existing ESP and construction of the AHPC will occur during Big Stone Plant's 5 ½ week outage from 9/16/02 – 10/25/02. In order to meet this time schedule, the project must advance in parallel through each of the five categories. The overall time table for the AHPC retrofit is shown in Appendix D.

2.7 Project Milestones

The following list describes the major milestones of the project.

Table 1 Milestone Chart

AHPC Milestone Chart	
Description	**Completion Date**
Task 1 - AHPC Design	
1. Layout Drawing	February 28, 2002
2. Workshop Drawings	February 28, 2002
Task 2 - AHPC Installation	
1. Initial shipment of materials	July 31, 2002
2. AHPC initial workforce on site (SEI & ELEX)	July 31, 2002
3. 90% Construction Materials On-Site	August 31, 2002
4. Plenums, ductwork, and internal components 60% prefabricated	September 16, 2002
5. Demolition Activities	September 30, 2002
6. Construction Activities	October 25, 2002
7. Installation of Filter Bags	October 25, 2002
8. Cold Commissioning	October 25, 2002
9. Hot Commissioning	October 26, 2002
10. Turn over unit to Big Stone Power Plant	December 1, 2002
Task 3 - AHPC Operations and Testing	
1. Complete first sampling activity	December 31, 2002
2. Remove bags for Laboratory analysis*	May 31, 2003
3. Complete second sampling activity	June 30, 2003
4. Remove bags for laboratory analysis*	September 30,2003
5. Complete Third sampling activity	May 31, 2004
6. Remove bags for Laboratory analysis*	May 31, 2004
*Bag removal activity to coincide with Big Stone Plant scheduled outages	

2.8 Work Plan

A work plan was developed to reflect the three Tasks of the project as described above. Nearly 95% of the cost of this project is a fixed cost contract and nearly all of that is scheduled for Task 2. The work plan was developed under the Earned Value Management System (EVMS). The EVMS allows DOE and Otter Tail Power Company (the participant in this project) to monitor the performance of a project in terms of what is actually being accomplished compared to what was planned to have been accomplished as of a status date. EVMS goes one step beyond comparing the actual cost with the planned cost and actual schedule with the planned schedule. EVMS integrates the three side of the “project triangle” scope (or work), cost and schedule, to help the project team determine project performance.

2.9 Performance Baselines

2.9.1 Technical Baselines

The technical baselines considered would be based on the most recent particulate emissions test performed at the plant prior to the AHPC installation, ID Fan Power, Air Compressor Power, and the typical electrical reading of the existing TRs. All other technical apparatus will be new and no comparison can be made.

2.9.2 Cost Baselines

Our current cost baselines will be based on electrical energy requirements taking into account three key factors; Electrical energy usage inside the precipitator, compressed air, and ID Fan power.

The hourly history of the following data was retrieved from the Big Stone Plant Performance Monitor. It was sorted for gross plant output of greater than 100 MW, and any other anomalous data. The following table summarizes that data.

Table 2 Summary Average of Precipitator Energy Usage (hourly)

Average Gross Load = 439.2 MW, Period = 1/1/2001 – 6/30/2002

Precip 1A	**Precip 1B**	**Precip 2A**	**Precip 2B**	**Total**
188.8 KW	190.4 KW	172.3 KW	133.0 KW	684.5 KW
ID Fan A	**ID Fan B**	**ID Fan C**	**ID Fan D**	**Total**
1,552.0 KW	1,567.6 KW	1,541.7 KW	1,573.9 KW	6,235.2 KW
Air Compressor D	**Air Compressor E**	**Air Compressor F**	**Total**	
105.5 KW	87.2 KW	127.9 KW	320.6 KW	

The ongoing maintenance costs of the existing precipitator are charged using Otter Tail Power Company's ORACLE financial management system. The twelve months prior to the outage, and the prior calendar year were reviewed and the total costs summarized.

Table 3 Miscellaneous Costs of Precipitator

Time Period	Labor and Materials	Humidification Chemical	Per Month average
6/1/2001 – 6/1/2002	$47,904.41	$80,892.69	$10,733.09
1/1/2001 – 1/1/2002	$68,886.94	$84,266.21	$12,762.76

Included in the Advanced Hybrid™ Filter cost analysis is the cost associated with the installed filter bags. The cost will be presented on an annualized basis, using the purchase price and factoring in the estimated life of the filter bags.

A minimum of nine filter bags will be sampled every six months (coinciding with the plant's spring and fall outages) for strength evaluation. Using the Mullen Burst Strength test apparatus, the samples are subjected to an increasing force in the z-direction (perpendicular to its surface) until the filter bag material fails. The pressure is recorded and compared to the benchmark of the new filter bag material. Plotting the results versus time over the course of the first few years of sampling provides the basis for predicting the life of the filter bags.

Mullen Burst Strength (psi)

Table 4 Matrix of Bag Test Results to be completed

Filter bag sample number	New	Spring 2003	Fall 03	Spring 2004	Fall 2004
1					
2					
3					
4					
5					
6					
7					
8					
9					
Ave					

2.10 Analytical Plan

The test program will involve comparison of parameters from actual operational data prior to and after installation. With regards to AHPC performance, the comparisons will be made on two factors, opacity and particulate measurement through the widely accepted EPA Method 5/17 analysis.

In addition to the comparisons of opacity and particulate measurement, the testing plans for more detailed flue gas sampling is described in section 3.4.

The specific operational information with regards to ID fan, air compressor, and TR power consumption, differential pressure across the bags, and bag life will be documented (see section 2.9.2).

3.0 PROCESS DESIGN CRITERIA

3.1 Process Description

The AHPC combines the concepts of both ESPs and FFs into a single device.

3.1.1 Existing ESP

Wheelabrator-Frye Inc. designed Big Stone Plant's existing ESP in 1975. The design includes four main chambers each consisting of four collecting fields, each field measuring 40 ft high by 45 ft wide and 14 ft deep. Guillotine type inlet and outlet dampers are used to close off a chamber should the need arise. Each field contains alternating rows of discharge electrodes and collecting electrodes. The discharge electrodes are star wires mounted on pipe frame supports. They help generate an ionizing field through which the flue gas must pass. The collecting electrodes are wide, thin plates arranged in 46 rows creating 45 possible gas passages through the field. These grounded plates attract charged particles out of the passing flue gas. The electrodes are energized by a transformer/rectifier (TR). The microprocessor controlled TR converts 480 V AC to 55 kV DC. This voltage is high enough to ionize the gas molecules close to the discharge electrodes. The electrodes must be periodically cleaned to remove any buildup of particulate. This is accomplished through the use of rappers. Collecting electrodes are rapped with a tumbling hammer arrangement while the discharge electrodes use a falling hammer/cam-drop style of rapper. Large hoppers are underneath each field to collect the particulates.

The basic operational mode of the ESP starts with flue gas entering the first fields of each of the four main chambers simultaneously. The gas passes through a high- density ionizing field generated by the TR and discharge electrodes. Particulates suspended in the gas collide with the ions and gain an electric charge. As the charged particulates flow across the grounded collecting electrode plates, the particulates are attracted to the plates and removed from the flue gas. At timed intervals, the rappers will strike the electrodes and dislodge any buildup of particulates. The particulates fall into the hoppers and are pneumatically fed to a flyash silo.

3.1.2 AHPC Retrofit

The Big Stone Plant's current ESP will be converted into an Advanced Hybrid Particulate Collector. The AHPC will use the same four main chambers, each containing four compartments. The first compartment will remain an ESP field; however, the ionizing field will not be active. We intend to demonstrate the technology as designed because a newly installed AHPC would likely not have a precipitator field installed in front of it. The following three compartments in each chamber will be updated to AHPC compartments. Guillotine type inlet dampers will be used to close off a chamber should the need arise, while louver type dampers on each compartment will be used to isolate the compartment if needed. Each of the compartments contains rows of discharge electrodes, collecting electrodes and filter bags.

The discharge electrodes differ from those used in the ESP in that they are rigid rather than wire. Their role, however, is the same; they generate an ionizing field through which the flue gas must pass. There are 19 rows of discharge electrodes with each row containing 15 electrodes. The rigid electrodes are mounted on a frame, which hangs from four electrical insulating supports. The collecting electrodes are wide, thin perforated plates arranged in 39 rows creating 38 possible gas passages through the compartment. Each row of collecting electrodes is made up of seven plates. The same microprocessor controlled TRs will be used to convert 480 V AC to 55 kV DC. The electrodes must still be periodically cleaned to remove any buildup of particulate. Both types of electrodes will use a tumbling hammer arrangement to accomplish this. Two rapper drive motors will be mounted outside the compartment, one for the collecting electrode hammers and the other for the discharge electrode hammers. A shaft on which the rapping hammers are mounted extends inside and across the compartment. The 39 collecting electrode hammers (one per row) and 19 discharge electrode hammers are mounted on their respective shafts.

Filter bags will be located between the perforated collecting electrodes. The bags will hang from a tubesheet built in five sections. Each compartment has 419 or 398 bags for a total of 4902 filter bags in the entire AHPC. The bags also must be periodically cleaned to remove any particulate that is caked onto the bag. Air headers located above each compartment receive compressed air from the existing plant air compressors. The 42 pulse jet valves (two per each of the 21 bag rows) control an air pulse from the header to the filter bags. One valve pulses the first 10 bags in the row and the second valve pulses the remaining 10 bags. When the valves are opened, the pulse of air that is released initiates a shockwave, which dislodges the particulate from the bag. The same ESP hoppers will be reused underneath each compartment to collect the particulates.

The basic operational mode of the AHPC starts with flue gas entering each of the 12 compartments. The gas passes through the high density ionizing field generated by the TR and discharge electrodes. Particulates suspended in the gas collide with the ions and gain an electric charge, just as they did in the ESP. The charged particulates must flow through the holes in the perforated collecting electrode plates. The particulates are attracted to the plates and removed from the flue gas. The gas then passes through the filter bags, into the clean air plenum and out of the compartment. The bags capture any remaining particulate as the gas passes through. At timed intervals, the rappers will strike the electrodes and dislodge any buildup of particulates. The pulse jet valves will periodically blast a high-energy pulse of air into the bag and the resulting shockwave will remove any buildup of particulate on the bag. The particulates fall into the hoppers and are pneumatically fed to a flyash silo.

3.2 Flow Simulation

Computational Fluid Dynamic (CFD) analysis was used in designing the AHPC to determine how well the gas flow is distributed to the compartments and also to ensure the gas velocity is not too high. Due to computer capacity, not every bag could be individually simulated. The bags of one row had to be summarized together with the collecting electrodes as a unit.

The first simulation was performed on a model without internal baffles to observe the general behavior of the gas flow inside the AHPC (see Appendix C).

The results of this simulation show that the gas flow is distributed evenly to the AHPC compartments. The reason for this even gas distribution is attributed to the high pressure drop across the bags compared with the very low pressure drop of all other internal equipment. The simulation also shows the gas flow to compartments 2 and 3 of every chamber passes below compartment 1 and not through compartment 1. The analysis showed that there is a zone below compartment 2 very close to the bags with higher velocity; however, the velocity is within limits.

The second simulation included the introduction of baffles and the collecting plate rapping devices. This model gives the simulation that is closest to reality (see Appendix C).

The results of this simulation show that the gas flow is still distributed evenly to the AHPC compartments. The baffles have a big influence on reducing the velocity of the gas flow below the first AHPC compartment. The gas velocity is within limits throughout the AHPC with the highest gas velocity near the hoppers. Based on this simulation, no additional baffles were deemed necessary.

3.3 Process Flow Diagram

The AHPC is designed to process 1,824,000 acfm of flue gas. The inlet temperature of the flue gas will range from 250-380 ^{o}F with the average temperature being around 290 ^{o}F. The total pressure drop across the entire AHPC, including dampers, ductwork, and tubesheets is 10 in WG. With an inlet loading of 1.5

grains/scf, the AHPC will yield an outlet loading of < 0.002 grains/scf for a collection efficiency of 99.99%. The particulate removed averages 14,800 lb/h. These design parameters are outlined in the process flow diagram shown in Appendix B.

3.4 Sampling Protocols and Analytical Methods

To prove the AHPC's superior fine-particle capture and particulate-bound trace element capture, the flue gas will be sampled at both the inlet and outlet of the AHPC for a minimum of three times during the 24 months of actual operation of the AHPC. The sampling activities are listed in Table 5. The first sampling period will be about 1 month after the operation of the AHPC has stabilized, the second after about 8 months of operation, and the final sampling period after about 18 months of operation. As shown in Table 5, the sampling activities will establish both the total particulate collection efficiency (EPA Method 5/17) and the fine particulate collection efficiency (multicyclones) of the AHPC. In addition, EPA Method 29 will be completed at the inlet and outlet to measure the AHPC collection efficiency for trace elements. The trace elements that will be measured are mercury, arsenic, lead, selenium, nickel, chromium, and cadmium. The analysis technique (except for mercury) will be ion coupled plasma–mass spectroscopy. Cold-vapor atomic absorption will be used to analyze the samples for mercury. It should be noted that only total mercury will be measured. In addition to using multicyclones to measure particle-size distribution, an APS and scanning mobility particle sizer (SMPS) will be used at the AHPC outlet. These instruments determine the particle-size distribution and the number of particles in a given gas volume for particles ranging from 0.03 to 15 µm.

Table 5 Flue Gas Sampling to Be Completed for Each Test Period

Method	Sampling Location	No. Samples	Results
EPA Method 5/17	AHPC outlet	3	Total fly ash mass loading
EPA Method 29[2]	AHPC inlet	3	Trace elements[1]
EPA Method 29	AHPC outlet	3	Trace elements[1]
Multicyclone	AHPC inlet	3	Size-fractionated mass loading
Multicyclone	AHPC outlet	3	Size-fractionated mass loading
APS/SMPS	AHPC outlet	3	Particle-size distribution

[1] Trace elements analyzed for will be total mercury, cadmium, arsenic, lead, nickel, chromium, and selenium.
[2] At the inlet, EPA Method 29 will provide the total fly ash mass loading.

3.5 Host Site Modifications

3.5.1 Ductwork

The new ductwork required is broken into two sections; clean gas plenums and ductwork. With the present arrangement, the dust-laden flue gas travels through the existing ESP in a typical horizontal direction. The new path of the flue gas will be to enter the AHPC horizontally, and then turn upwards as it travels through the AHPC components, through the bags, where it moves into a clean gas plenum, and then it will travel horizontally through the clean gas ductwork and then angle downward again where it re-connects with the existing ID Fan suction duct.

Each flue gas path though the precipitators is called a chamber and each chamber has four fields in the direction of gas flow. The AHPC modification will be done on the back three fields of each chamber. There is no planned modification of the existing inlet field, as it is not anticipated to be in use.

Each AHPC compartment will have a clean gas plenum where access to the bags occurs. The approximate size of each plenum is 20’ x 40’ x 14’. The floor of this plenum is the bag tube sheet. The exit of the plenum will have a damper so that flow through this field can be isolated for compartmentalized reasons.

After the gas leaves the plenum and travels through the isolation damper, it will travel through the clean gas ducts and re-connect with the existing ID Fan suction duct. The approximate size of the clean gas ducts (4 total) is 17' x 70' x 8'.

These ducts will need to be designed to carry full ID Fan suction pressure (30 INWG.) It is anticipated that these ducts will require expansion joints and supports, and will require insulation and lagging to minimize corrosive attack due to sulfur containing flue gas.

Final engineering will be required from the U.S. contractor on these components.

3.5.2 Utilities

The only utilities required for the AHPC are compressed air and the lighting.

The compressed air will be supplied from the existing compressor system at the Big Stone Plant. A humidification system was purchased to aid in flyash collection of the precipitator. Three new compressors were purchased for this system. It is the intention of the Big Stone Plant to eliminate the humidification system once the AHPC system is installed. The only design information will be the route of the compressed air pipeline from the existing compressor station (first floor of the main plant building), to the compressed air headers at the top of the AHPC structure for bag cleaning apparatus. The approximate length of this route is 300 ft.

There is lighting on the existing precipitator, and it is anticipated that the AHPC will have similar lighting as needed.

3.5.3 Electrical and Control Systems

The electrical energy requirement for the AHPC will center on the energy to the high voltage equipment in the box. The existing ESP uses 6 transformer/rectifier (TR) sets per chamber. The AHPC system requires only three per chamber, although a fourth will remain in place in case the inlet field needs to be run. The cables feeding these TRs will need to be removed and replaced during construction. The TRs themselves will need to be removed from the roof, inspected and painted, and then lifted back up to the top of the precipitator for re-installation.

The control system will be a combination of local and centralized control systems.

The existing TR controls will remain in place. Local “slave” controllers will control the individual compressed air pulse valves. These controllers will get their input to begin a pulse sequence from a local “master” control box.

The “master” control box will need to interface with Big Stone’s central control system. The central control will actuate each field damper, measure and output the differential pressure across the bags, measure compressed air pressures, and other miscellaneous supervisory functions.

3.5.4 Demolition Plan

Although the demolition and construction of this project is the most detailed area, the scope of this report is to summarize, in general, the plan to build the AHPC. The demolition is best summarized by the following list:

- Adjust hot purge air piping presently feeding all of the roof girders.
- Remove all conduit, cable trays, wiring, disconnect switches, etc., feeding the electrode and collecting plate rapper motors, insulator heaters, roof lighting, and TRs.
- Remove all access (stairs and ladders) located on weather roofs and roof girders as far as necessary.
- Disconnect and remove rapper insulators inside of roof girders.
- Disconnect and remove existing electrode rapper cam release mechanisms from top of roof girders.
- Adust TRs, bus piping, and bus ducts.
- Remove insulation and lagging from tops, sides, and ends of roof girders.

- Remove corrugated weather roof sections including support beams to expose hot roof insulation.
- Remove blanket insulation from top of hot/gastight roofs.
- Remove hot/gastight roofs.
- Remove electrode pipe frames.
- Remove collecting curtains with collecting curtain support beams and rapper bars attached.
- Remove collecting curtain rapper shafts, hammers, bearings, and rapper drives.
- Remove electrode high voltage support frames not used for AHPC including rapper shafts and bearings.
- Remove all interior anti-sneak baffles in ESP Fields 2–4 from top of unit and vertical baffles from along the sidewalls.
- Remove sidewall insulation and lagging as required for new collecting plate rapper driveshaft penetrations in AHPC sections.
- Remove existing Kirk-type safety key interlock system from all control cabinets and doors.
- Remove all manholes including insulation cover and frames.

3.5.5 Construction Plan & Installation Plan

The following list of items best describes construction and installation:

- Adjust high-voltage support frames and install new support insulators.
- Install new collecting curtains, upper support beams, and rapper bars.

- Install new access doors at collecting plate rapper drive elevation and replace existing ones in stainless steel material.
- Install new internal walkways at collecting curtain rapper shaft level with lower curtain guides.
- Install new collecting curtain rapper drives, shafts, bearings, and hammers.
- Install new rigid discharge electrode frames, including upper supports and lower guides.
- Install new high-voltage rapper drives, shafts, bearing, and hammers.
- Install new gastight roof/pulse filter tube sheets.
- Install new walk-in clean air housings including air headers, pulse valves, piping, etc. Also install filler plates between girders to complete gastight housings.
- Relocate existing roof girder doors to clear clean air plenum partitions.
- Install new clean air plenums, dampers, and expansion joints
- Install new ductwork and expansion joints to existing ESP outlet transition nozzle flanges.
- Install any required internal gas distribution devices or baffles for flow control.
- Install new pulse filter bags and two-piece split cages.
- Install new pulse pipes.
- Adjust roof as platform to air headers.
- Install insulation and lagging on new clean air housings and outlet ductwork to nozzles.
- Repair any other areas of insulation and lagging disturbed by the rebuild work.

- Install new safety key interlock system covering entire system of doors, TR control cabinets and TRs.

- Install new control panels, wiring, conduit, cable trays, local disconnects, etc., for the rapper motors, insulator heaters, TRs, damper drives, pulse valve solenoids, new instrumentation.

- Install devices necessary for the precoating of the bags.

- Cold and hot test run by ELEX commissioning engineers including adjustment of controls and optimization of the entire operation as well as the training of plant personnel.

3.6 Project Coordination and Work Force Issues

Project coordination and direction will be completed by Otter Tail Power Company personnel. ELEX AG, as the prime Engineering and Fabrication contractor will take the lead in all technical issues related to the AHPC. The fabrication of components and some of the engineering will be completed by a U.S. company.

4.0 PROCESS DRAWINGS

Drawings of the AHPC are included in Appendix B.

5.0 EQUIPMENT

5.1 Detailed Equipment List

Table 6 Detailed Equipment List

Group	Description	No.	Technical data
ESP components	Inspection doors	24	ELEX standard
	Collecting electrodes	3108	Perforated, 590 x 7500 mm
	Discharge electrodes	6364	ELEX RS, rigid type, 3800 mm
	Supporting insulators	48	Coorstek, 14.75 x 12.6 x 20.0", AD85
	Geared motors for collecting electrodes rapping system	12	SEW, type S77DT90L8, 0.55 kW
	Rapping hammers for collecting electrodes	462	ELEX standard
	Geared motors for discharge electrodes rapping system	12	SEW, type RM67DT71D8, 0.15 kW
	Rapping hammers for discharge electrodes	222	ELEX standard
	Rapping insulators	12	ELEX standard
	Pin wheel drive	12	ELEX standard
	Insulation door	24	ELEX standard
Gas ducts	Dampers	12	Motor drive
	Flexible joints	36	
AHPC components	Walk in plenums	12	Incl. tube sheets
	Cages	4902	275.625 x 6", mild steel
	Pulse pipes	504	3"
	Venturi nozzles for pulse pipes	4902	Goyen, for 3" pipes
	Headers	24	Goyen, 14" diameter x 15' length
	Full immersion valves	504	Goyen, type RCA76MM, 3"
	Solenoid enclosures	72	Goyen, 7 solenoids 24VDC, 1 heater 110VAC

5.2 Equipment Weights

Comparison table

	Load for 1 compartment		
	Existing ESP	AHPC	
	kg	kg	
Collecting electrodes	84,210	27,710	with 10 mm dust
Suspension bar collecting electrodes	7,886	2,958	with 10 mm dust
Suspension of discharge electrodes	34,273	10,500	with 6 mm dust
Under girder with mounting platform	0	1,600	with 6 mm dust
Bag	0	8,767	
Cage	0	2,785	
Plenum with insulation	0	13,000	
Duct and flap with insulation	0	4,800	
Weather roof	2,000	0	
Total kg per 1 compartment	128,369	72,119	

5.3 ESP Components

5.3.1 Discharge Electrodes

The rigid discharge electrodes help generate an ionizing field through which the flue gas must pass. There are 19 rows of discharge electrodes with each row containing 15 electrodes. The rigid electrodes are mounted on a frame, which hangs from four electrical insulating supports.

5.3.2 Collecting Plates

The collecting electrodes are wide, thin perforated plates arranged in 39 rows creating 38 possible gas passages through the compartment. Each row of collecting electrodes is made up of seven plates. The charged particulates must flow through the holes in the perforated collecting electrode plates. The particulates are attracted to the plates and removed from the flue gas.

5.3.3 Transformer Rectifiers

The same microprocessor controlled TRs will be used to convert 480 V AC to 55 kV DC. The electrodes must still be periodically cleaned to remove any buildup of particulate. Both types of electrodes will use a tumbling hammer arrangement to accomplish this.

5.3.4 Rapping Systems

Two rapper drive motors will be mounted outside the compartment, one for the collecting electrode hammers and the other for the discharge electrode hammers. A shaft on which the rapping hammers are mounted extends inside and across the compartment. The 39 collecting electrode hammers (one per row) and 19 discharge electrode hammers are mounted on their respective shafts.

5.4 Filtration Components

5.4.1 Tube Sheets and Filter Bags

Filter bags will be located between the perforated collecting electrodes. The bags will hang from a tubesheet built in five sections per compartment. Each compartment has 419 or 398 bags for a total of 4902 filter bags in the entire AHPC.

5.4.2 Pulse Jet System

The bags also must be periodically cleaned to remove any particulate that is caked onto the bag using the pulse jet system. Air headers located above each compartment receive compressed air from the existing plant air compressors. The 42 pulse jet valves (two per each of the 21 bag rows) control an air pulse from the header to the filter bags. One valve pulses the first 10 bags in the row and the second valve pulses the remaining 10 bags. When the valves are opened, the pulse of air that is released initiates a shockwave, which dislodges the particulate from the bag. The same ESP hoppers will be reused underneath each compartment to collect the particulates.

6.0 ES&H CONSIDERATIONS

It will be required by the contractors on site that all OSHA regulations pertaining to a generating facility be followed. The on-site contractor shall have a safety and health person under their employ at the job site to assure Otter Tail Power Company that the contractor is not in breech of contract with regards to following OSHA safety policies.

The project site is in a rural area with the closest town being about 2 miles to the southeast. It is unlikely that were would be any noticeable change in noise level during construction.

Typical traffic due to construction would increase around the plant with shipments and contractors driving to the site. The plant is located near U.S. Hwy 12 so the impact of the additional traffic would be minimal.

An Environmental Assessment was completed (DOE/EA-1418) for this project in June 2002.

7.0 COSTS

7.1 Project Costs

The overall project cost is $13,353,288. This is further described in the following sections.

7.2 Capital Costs

The capital cost of this project is defined by two major components, the contract with ELEX AG, as well as the contract with W.L. Gore and Associates. The contract with ELEX AG includes design, demolition, and construction of nearly the entire project. The only large capital items not included with the ELEX contract are the filtration bags. The purchase of the filtration bags is direct with W.L. Gore and Associates. The capital breakdown is as follows:

ELEX AG Contract	$ 9,100,000
W.L. Gore and Associates Contract	$ 2,670,963*
Taxes	$ 596,000
Total Capital	$12,366,963

*Although this is the negotiated price of the bags, W.L. Gore and Associates is reducing the cash required by $870,963, to count as cost sharing on the project.

7.3 Project management costs

Project management costs will encompass the in-kind services from Otter Tail Power Company and W.L. Gore and Associates. The total cost of this effort is $761,325. This figure is broken down by the following description:

OTP Labor (inc. fringe benefits)		$305,353
($193,177 – design and construction)		
($112,176 – operation)		
Gore Labor		$310,300
OTP Travel		$20,922
Gore Travel		$96,600
Minor Equip & Supplies	$28,150	
Total Management Costs		$761,325

7.4 Testing & Verification Costs

A testing team from outside the project team will conduct the verification and post installation testing. A descriptive list of the testing methodology is listed in section 3.4. The estimated cost of this effort is

$225,000. However, this figure may include some report writing and miscellaneous efforts not yet identified.

7.5 Operating and Maintenance Costs

7.5.1 Fixed Operating Costs

There is one labor component that may be considered a fixed cost. We have estimated the Big Stone Plant Operators will spend roughly 1.25 hours per day checking over the system while it is in operation. This would cover routine rounds and inspection while operating. This cost is included in the estimate of OTP labor above.

7.5.2 Variable Operating Costs

The significant variable operating costs will likely be the electrical power to the TR sets, the air compressors, the rapper motors, and the air transport blowers. There is additional energy required to run the balance-of - plant equipment to supply the AHPC with particulate. The main focus being the additional required energy of the ID fans because of the increase in pressure drop across the system.

The electrical energy of the rapper motors and air transport blowers is insignificant when compared to the TR sets and air compressor motors. The electrical conditions of the TR sets will be recorded at regular intervals, so it will be a known value. The amperage of the air compressors is also known. The other minor power usage items can be estimated based on nameplate information.

The additional ID fan power will also be documented. It is only the additional power and not the full ID fan power that will be attributed to the AHPC system.

Other variable operating costs will likely be the labor required for unforeseen maintenance issues and long-term maintenance. There are approximately 1500 hours included in the OTP labor estimate for assistance during the design phase, small construction issues, controls interface, and unforeseen maintenance issues that will require Big Stone Plant personnel expertise and labor.

8.0 PROJECTED PERFORMANCE

8.1 Projected Technical Performance

Technical performance will center around the following issues: particulate capture capability, power consumption, differential pressure, and component life. Particulate capture is covered under section 8.2.

The specific components to monitor in this regard are the filtration bags, solenoid puffer valves, rappers, and TRs (or electric field) performance. The balance of the components such as the dampers and associated drives, door system, and ash removal system are either not process critical or are not changing substantially.

The filter bags are the main critical component to watch for performance. The effects of true long-term operation of the bags are yet to be seen. The target dP for the bags is 8 INWG at 1,825,000 acfm of gas flow. Actual system pressure drop will be recorded on one-minute snapshots.

The issue of solenoid puffer valves is one of component life, as well as functionality for bag cleaning.

Rapper performance will coincide with electrical measurements of the TRs, which will be taken periodically to ensure the proper amount of ash removal from the emitting and collecting electrodes

8.2 Projected Environmental Performance

8.2.1 Air Quality

The U.S. Environmental Protection Agency (EPA) has established National Ambient Air Quality Standards (NAAQS) for the following seven criteria pollutants: ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), particulate matter less than 10 micron size (PM_{10}), particulate matter less than 2.5 micron size ($PM_{2.5}$), and lead (Pb). NAAQS are expressed as concentrations of pollutants in ambient air (Figure 2).

Particulate matter is the only criteria pollutant that would be affected by the AHPC project. Although previous data have indicated that vapor-phase trace metals can be effectively captured with sorbents in the AHPC without impairing performance, sorbent development is not an objective of the AHPC demonstration.

The NAAQS standards for particulate matter apply to statistical values of air quality that are derived from 3 years of data. Sufficient air quality data are not yet available for evaluating compliance with the $PM_{2.5}$ standards.

For areas that are in attainment with NAAQS, EPA has established standards for Prevention of Significant Deterioration (PSD) of air quality (40 CFR, Part 51.166). The PSD standards provide maximum allowable increases in concentrations of pollutants for areas already in compliance with NAAQS and are expressed as allowable increments in the atmospheric concentrations of pollutants. Allowable PSD increments currently exist for SO_2, NO_2, and PM_{10}.

One set of allowable PSD increments exists for Class II areas, which include most of the United States, and a more stringent set of allowable increments exist for Class I areas, which are defined under the Clean Air Act (Title 42, United States Code, Part 7472, Section 162) as international or national parks that exceed 6,000 acres in size, or national wilderness areas or national memorial parks that exceed 5,000 acres in size. These PSD increments are shown in the insert.

Figure 2 PSD Increments

Allowable Increments for PSD

Prevention of Significant Deterioration (PSD) increments establish the maximum allowable increases in pollutant concentrations in areas where the National Ambient Air Quality Standards have been achieved.

		Allowable Increment (mg/m^3)	
Pollutant	**Averaging Time**	**Class I Area**[1]	**Class II Area**[2]
SO_2	3 hr (max)	25	512
	24 hr (max)	5	91
	Annual[3]	2	20
NO_2	Annual[3]	2.5	25
PM_{10}	24 hr (max)	8	30
	Annual[3]	4	17

[1] Designated areas (e.g., international parks, national parks over 6,000 acres, national wilderness areas over 5,000 acres)
[2] Remainder of the United States
[3] Arithmetic mean

The EPA has also established New Source Performance Standards (NSPS) that set forth emission standards, monitoring requirements and reporting requirements for a number of individual industrial or emission source categories. The source applicability requirements are based upon date of manufacture and size of the unit. Big Stone Plant is not regulated under NSPS emission requirements.

Under Title III (Hazardous Air Pollutants) of the Clean Air Act Amendments (CAAA) of 1990, EPA was required to identify source categories or subcategories that emit any quantity of 189 chemicals initially listed for air toxics emission regulation. Subsequent to identification of these sources, EPA was required to issue National Emission Standards for Hazardous Air Pollutants (NESHAPs) based on use of “maximum achievable control technology” (MACT) for new sources (and possibly less stringent standards for existing sources). Emissions from specific source categories are contained in the NESHAPs (40 CFR, Parts 61 and 63).

The State of South Dakota has incorporated standards and procedures required by EPA into its environmental regulations. PSD, NSPS, and NESHAPs regulations have been incorporated into State law, and the State of South Dakota has adopted the NAAQS for all pollutants.

8.2.2 Solid Waste Quality

The Big Stone Plant currently has a solid waste permit from the South Dakota Department of Natural Resources that includes an ash fill site on plant property. The ash fill site is permitted through the South Dakota Department of Environment and Natural Resources for a maximum of 250,000 tons per year of ash generated from fuel combustion at the Big Stone Plant. This solid waste permit also contains a provision for the disposal of wood products, rubble, construction and demolition debris, and similar non-putrescible wastes from the Big Stone Plant in a Restricted Use Landfill, which is permitted to accept 100 tons per year.

Any debris from construction that was not consumed, salvaged, removed by the contractor, or placed in the Restricted Use Landfill, would be disposed of in a permitted landfill off site.

The types of wastes produced at the Big Stone Plant will not substantially change from current conditions as a consequence of operations of the proposed AHPC.

Subbituminous coal, and other alternative fuels are burned each year at the Big Stone Plant, which results in the production of fly ash and bottom ash. The landfill is permitted to accept up to 250,000 tons per year of these by-products. The total amount landfilled is dependent upon quantities of fly ash and bottom ash that are sold for beneficial uses and removed from the site. From 1997 through 2000 the amount of fly ash and bottom ash landfilled has ranged from 85,000 tons to 169,000 tons. This is well below the permit maximum of 250,000 tons per year.

The current ESP emits approximately 0.0045 grains/ACF of fly ash. The AHPC will remove 99.99% of the particulates in the stack gases and will emit approximately 0.0001 grains/ACF of fly ash. This will account for less than 300 tons of additional fly ash per year. This additional ash will not pose any problems for disposal.

8.2.3 Water Quality

Wastewater currently generated by operations at the Big Stone Plant is all handled on site. The plant is a zero discharge facility and therefore it does not have an NPDES permit. The cooling pond handles most of the wastewater on the site and holding and evaporation ponds are used to contain excess wastewater. A brine concentrator is used to process a portion of the wastewater. The treated water is returned to plant for reuse. There is an NPDES Stormwater permit for the site, but there has been no discharge from the site to date. Wastewater quantities will not change as a result of the AHPC installation.

9.0 COMMERCIAL APPLICATIONS

The market potential for this new technology exists in markets that have a large existing base of aging ESPs that need to be replaced or converted because of pending or tighter emission controls. Two such markets are the minerals (cement industry) and the coal-fired utility market. The choice between whether to replace or convert the existing ESP is a matter of trading lower capital costs with a conversion versus the cost of a longer outage associated with making the conversion. The size and condition of the existing ESP plays a factor in this decision. The decision is a very site-specific issue. The ADVANCED HYBRID™ filter is viable in either scenario. For new installations or for new stand-alone equipment to replace the existing ESP, the pulse jet fabric filter is the next best alternative to the ADVANCED HYBRID™ filter. For retrofits or conversions of existing ESPs, the COHPAC® system is the next best alternative to the ADVANCED HYBRID™ filter.

Several new jobs have been quoted in both markets, comparing an ADVANCED HYBRID™ filter to a pulse jet fabric filter. In all cases, the ADVANCED HYBRID™ filter has been the same or lower in capital cost than the pulse jet fabric filter. Additionally, the ADVANCED HYBRID™ filter requires approximately a 20% smaller footprint and has approximately one-third the number of higher maintenance, disposable components such as filter bags as a pulse jet fabric filter. This should lead to a more reliable, durable filter system. A recently quoted cement kiln application highlighted these advantages. This application requires only 756 GORE-TEX® membrane filter bags. This is almost 1800 filter bags less than a pulse jet fabric filter would need and the ADVANCED HYBRID™ filter would require at least a 20% smaller footprint.

Retrofit or ESP conversion jobs have also been quoted in North America and Europe comparing the ADVANCED HYBRID™ filter to a hybrid type filter, where a fabric filter is located downstream of an ESP. In those cases where the ESP was old and needed significant upgrades in order for the hybrid type filter system to function well, the ADVANCED HYBRID™ filter had the economic advantage. For example, the Big Stone conversion has a project cost for the overall filter system of $25/kW. It is anticipated that these costs will decline further as more systems are built and the design is further refined and optimized.

This technology will be positioned as an economically viable alternative to pulse jet fabric filters for new stand-alone installations and economically viable to the hybrid type filters for retrofits of existing ESPs that require a major rebuild of their inlet fields. In addition, the ADVANCED HYBRID™ filter provides a system that requires fewer components, that needs less space, and offers superior filtration efficiencies. The technology will be sublicensed to a select group of OEMs around the world. The license will allow them to practice the technology and to design and build systems in defined regions and markets.

The ADVANCED HYBRID™ filter provides many benefits, as listed in Table 7, when compared to existing particulate control technologies. It offers the reliability of an ESP with the emissions performance of a fabric filter that utilizes ePTFE membrane filter bags.

Table 7 Benefits of the ADVANCED HYBRID Filter

BENEFITS	REASONS
Lower Capital Cost	**Compact design, high A/C ratio, fewer components.**
Lower Operating Cost	**Fewer components, more reliable.** **Durable, high performance GORE-TEX® membrane filter bags.** **Comparable energy consumption costs.**
Lowest Emissions	**GORE-TEX® membrane filter bags.**
Fuel Flexibility	**The unique ESP and baghouse arrangement allows it to perform well over a wide range of plant operations.**

The construction of two, full-scale ADVANCED HYBRID™ filters is being completed based on excellent performance data from a field pilot unit. A new ADVANCED HYBRID™ filter located in Italy is scheduled to start up in September 2002. A full-scale demonstration unit retrofitted to an existing ESP on a coal-fired boiler located in Big Stone, South Dakota, is scheduled for completion and start-up in October 2002. This technology is easily adapted for new installations as well as retrofits of existing ESPs.

10.0 APPENDICES

APPENDIX A – References & Additional Pertinent Publications

APPENDIX B –Miscellaneous Drawings

APPENDIX C – Graphical Results of Flow Modeling

APPENDIX D – Overall Schedule

APPENDIX E – Pre-Outage Schedule

APPENDIX F – Mechanical Outage & Post Shutdown Schedule

APPENDIX G – Commissioning Schedule

APPENDIX A - REFERENCES & ADDITIONAL PERTINENT PUBLICATIONS

- Otter Tail Power Company Document – Volume II – Technical Application for "Demonstration of a Full Scale Retrofit of the Advanced Hybrid Particulate Control Technology". Submitted for the Power Plant Improvement Initiative, April 13, 2001

- Otter Tail Power Company Document – Volume I – Business and Financial Application for "Demonstration of a Full Scale Retrofit of the Advanced Hybrid Particulate Control Technology". Submitted for the Power Plant Improvement Initiative, April 13, 2001

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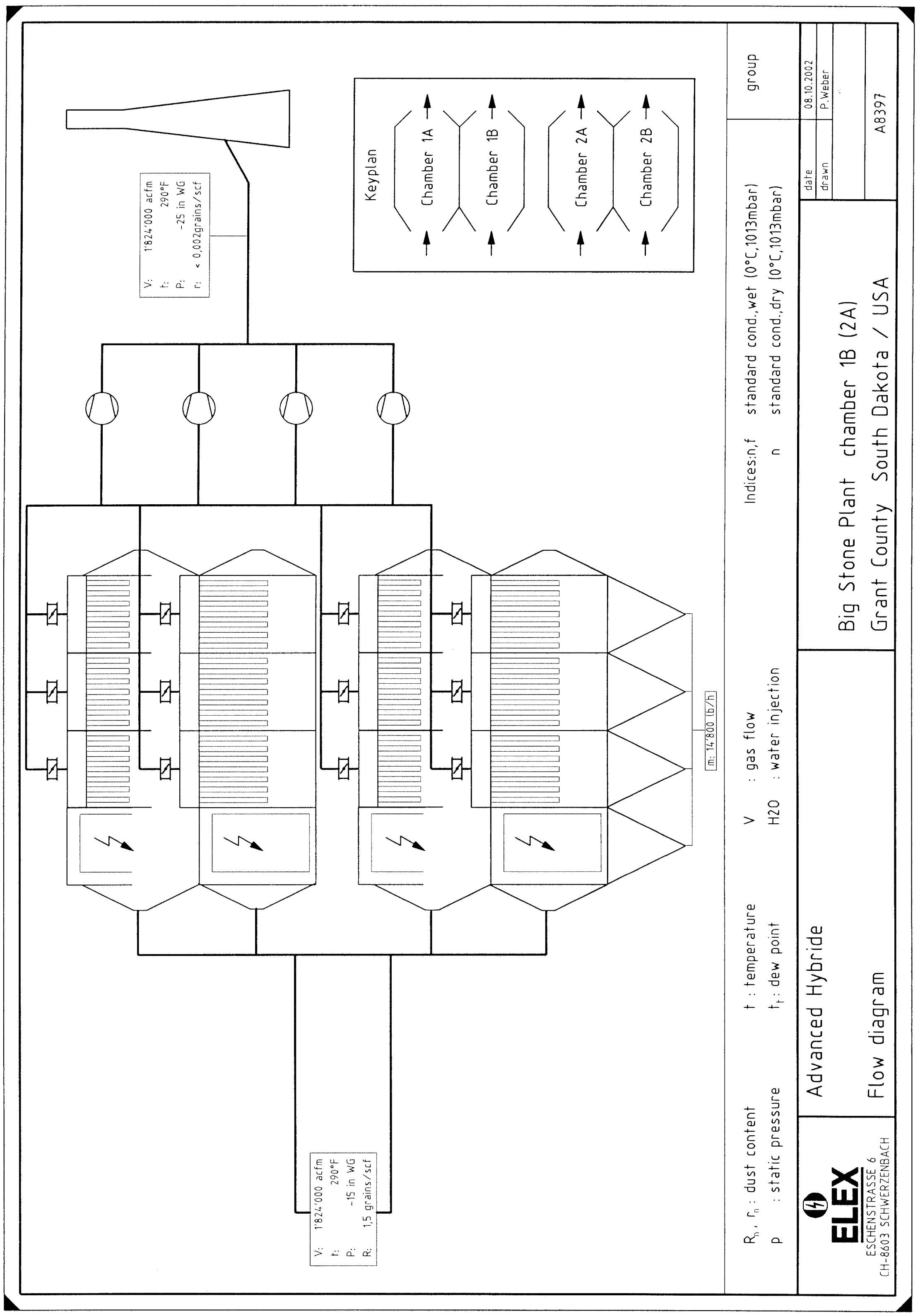
APPENDIX B - MISCELLANEOUS DRAWINGS

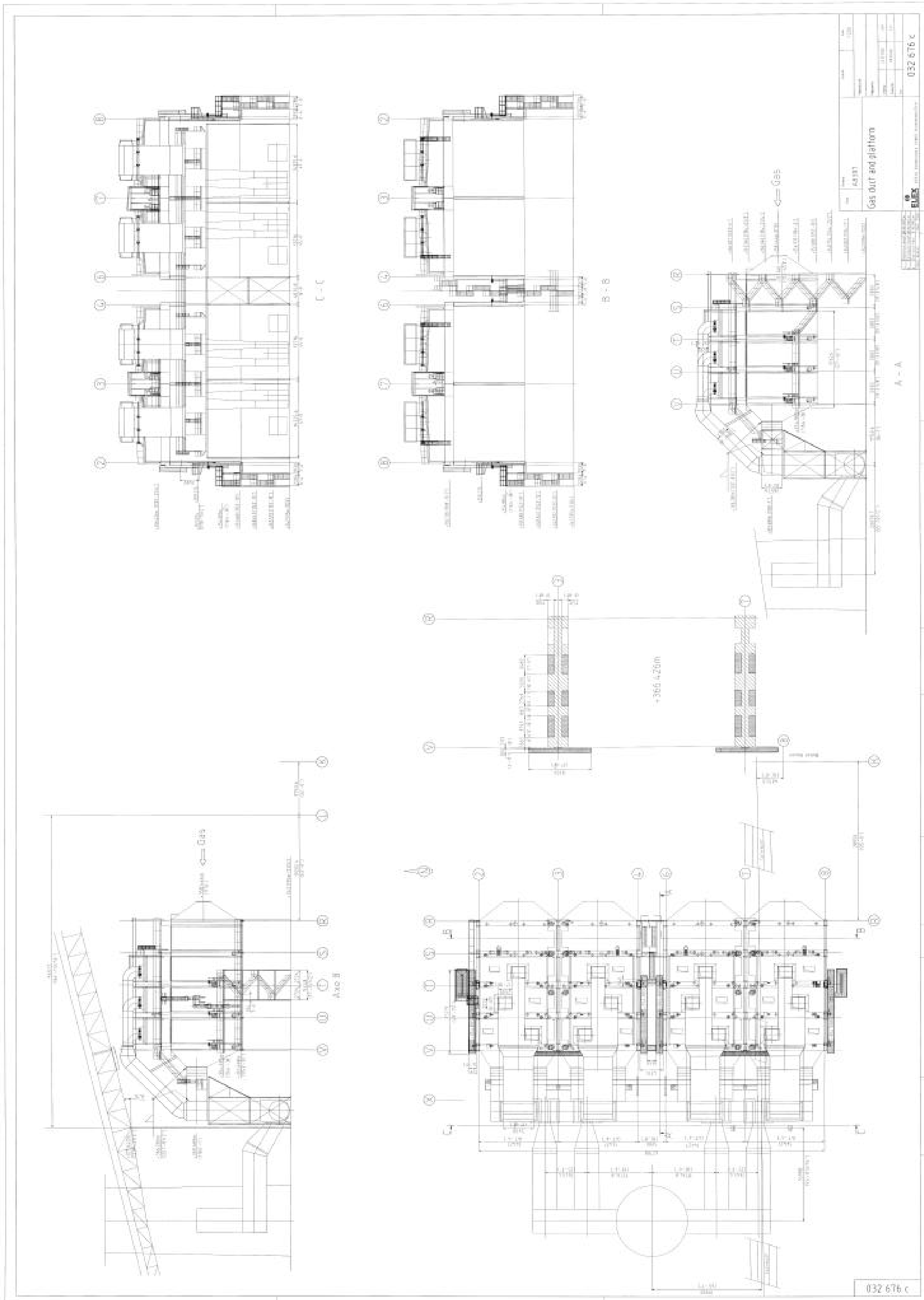
The following prints are included:

Print #	Description
A8397	Flow Diagram
032676c	Gas Duct and Platform
8397.02A	Assembly of Precipitator
8397.02B	Assembly of Precipitator
328052	P&I Diagram

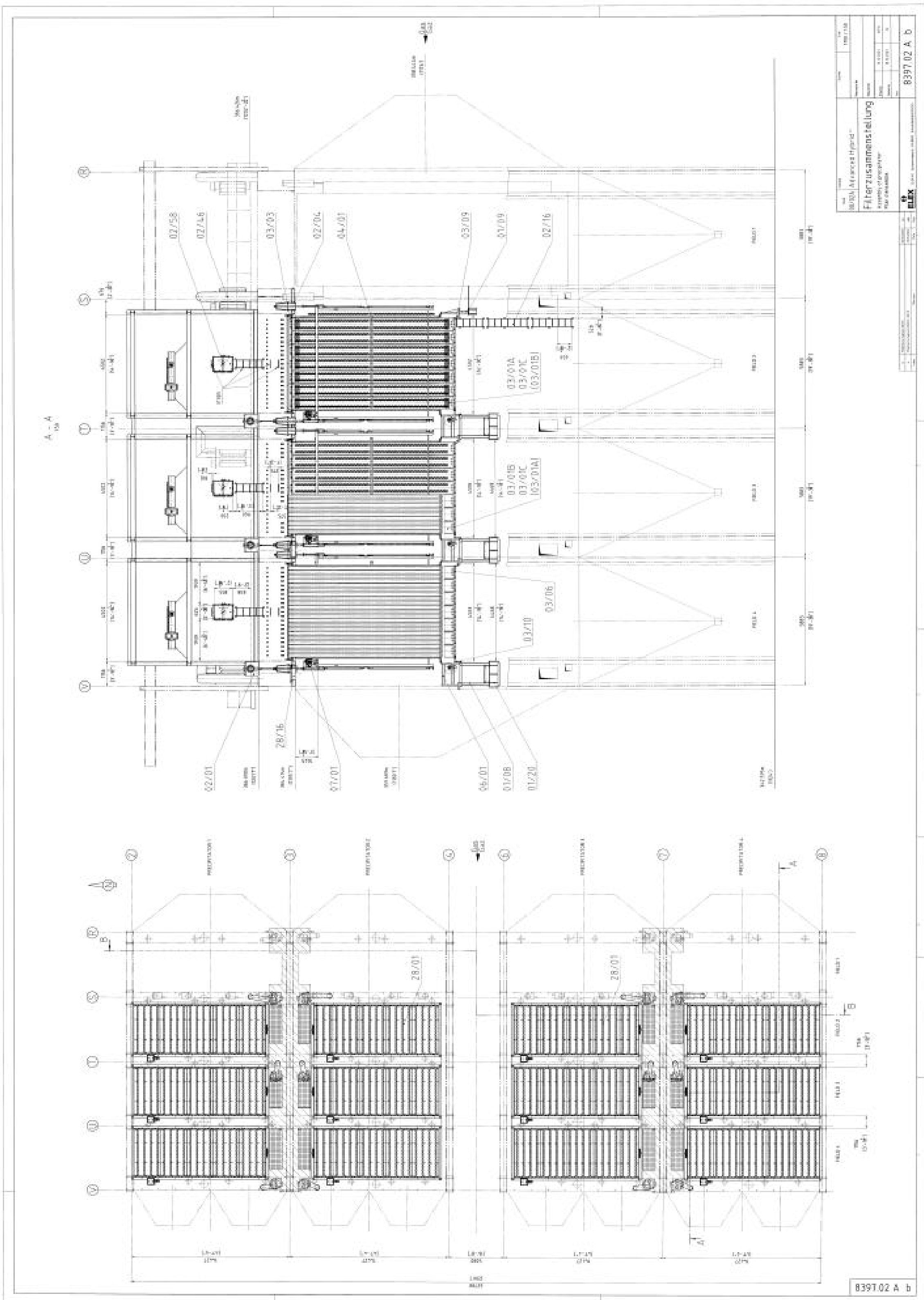
Photograph of Big Stone Plat Precipitator (Pilot Unit at Right)
Photograph of Pilot Unit at Big Stone



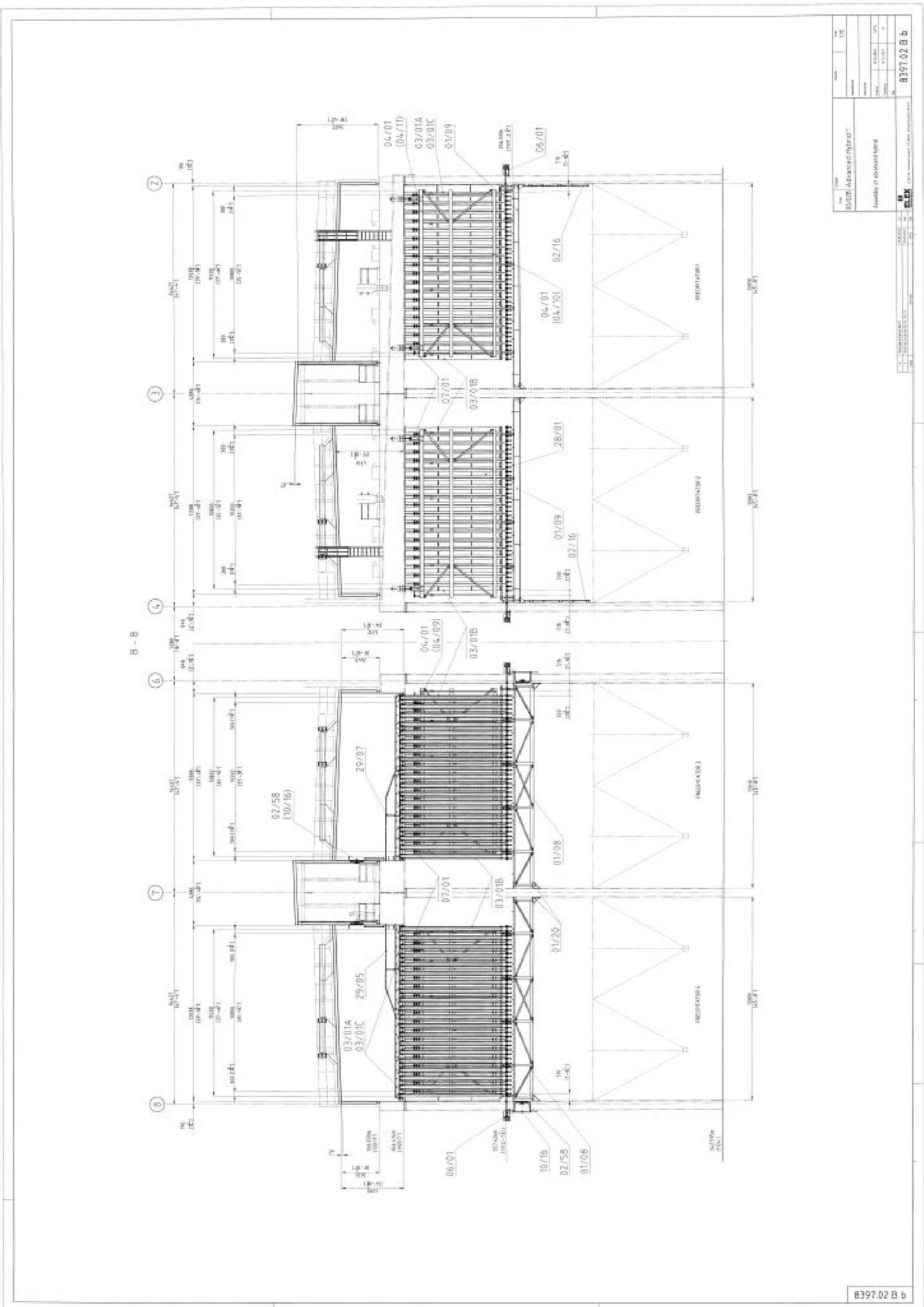
Drawing A8397 – Flow Diagram



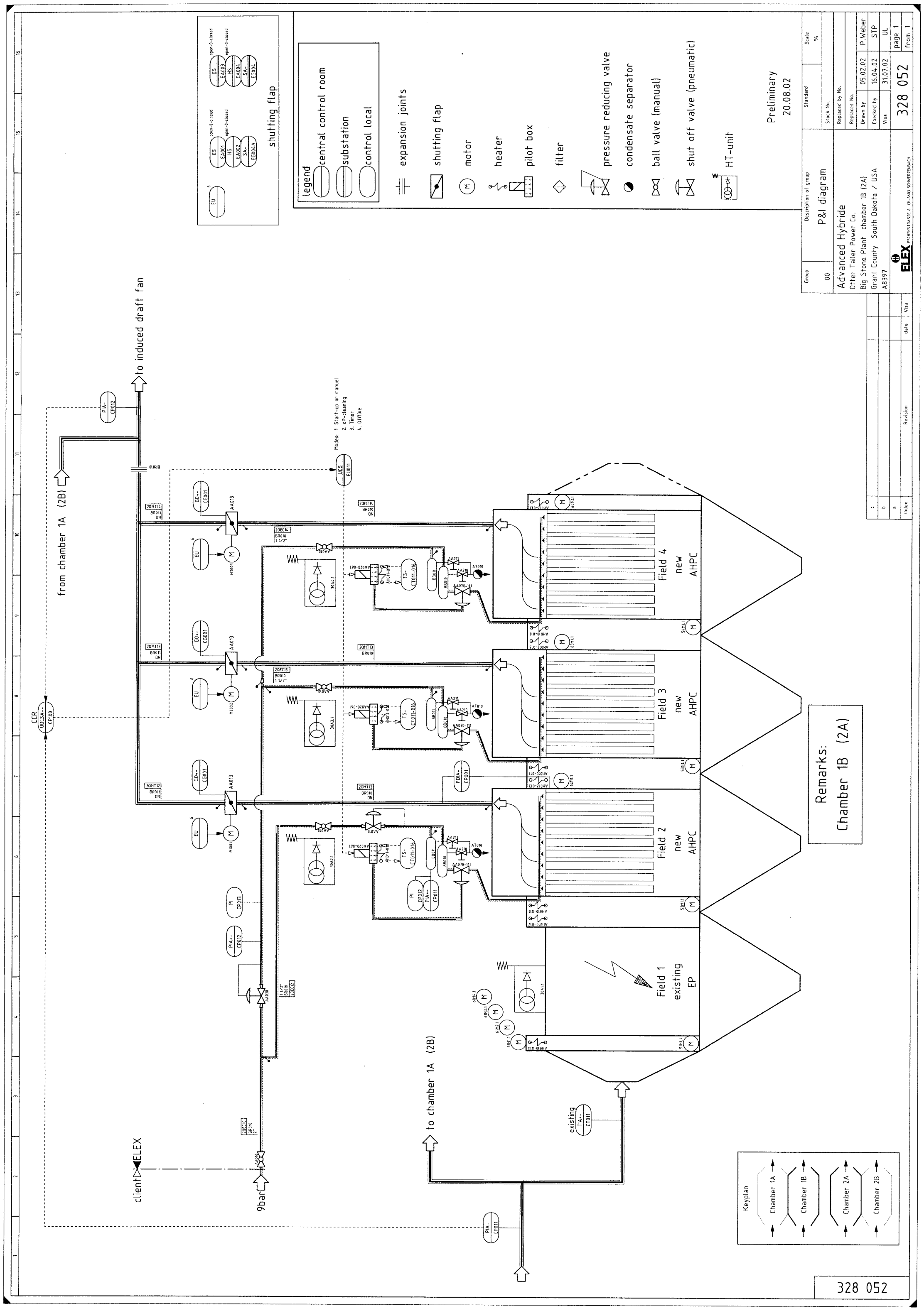
Drawing 032676 – Gas duct and platform



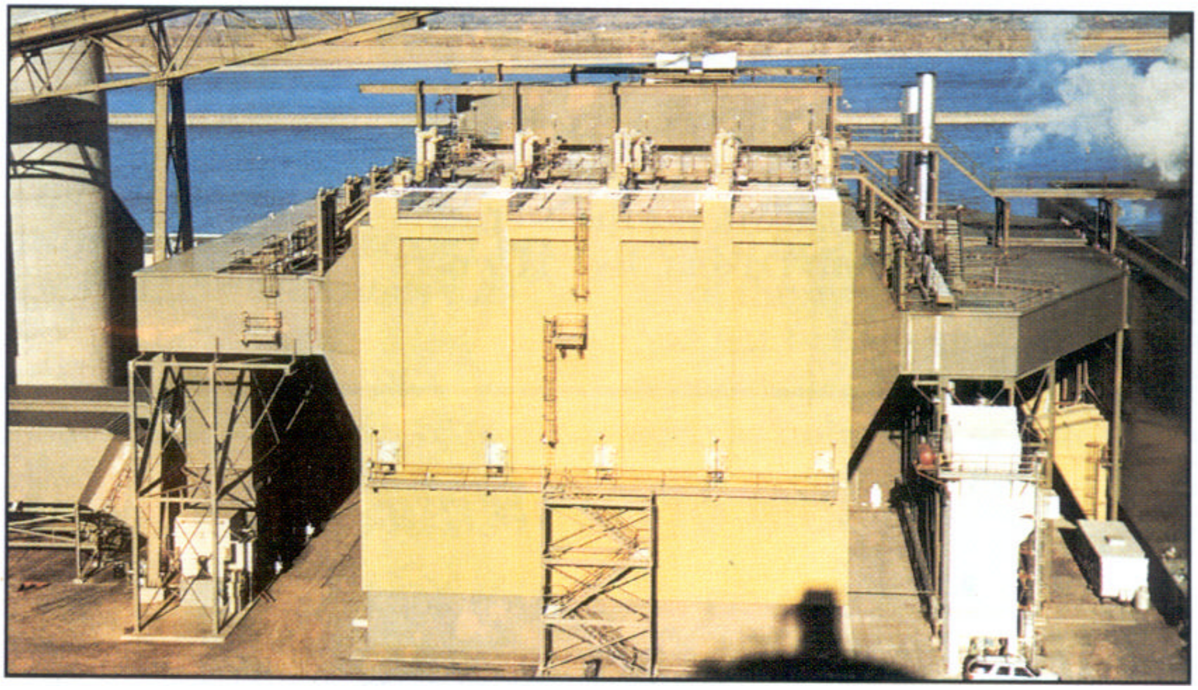
Drawing 8397.02A - Arrangement Drawing



Drawing 8397.02B - Arrangement Drawing



DRAWING 328052 - P&I DIAGRAM

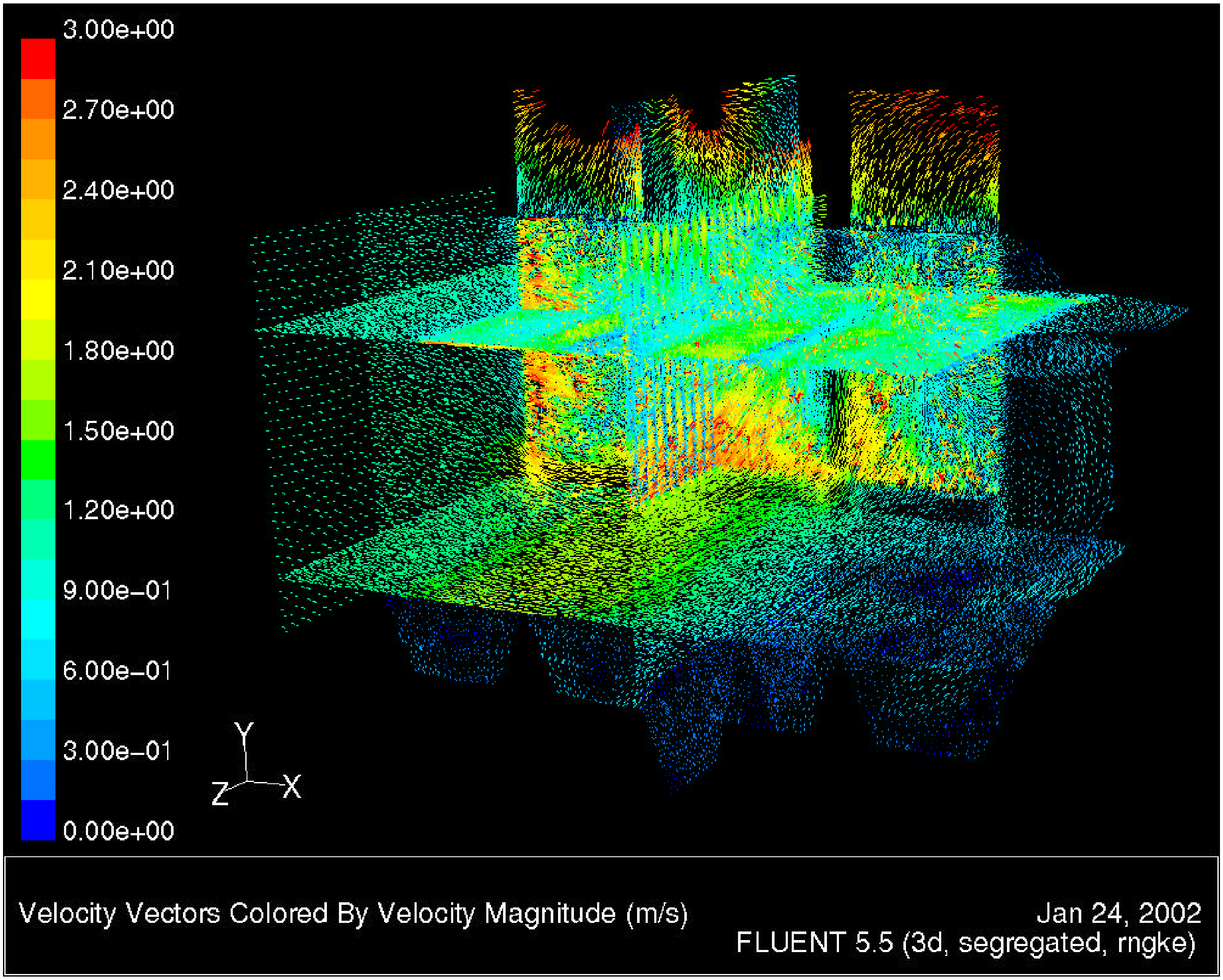


Photograph of Big Stone Precipitator (Pilot Unit at right)

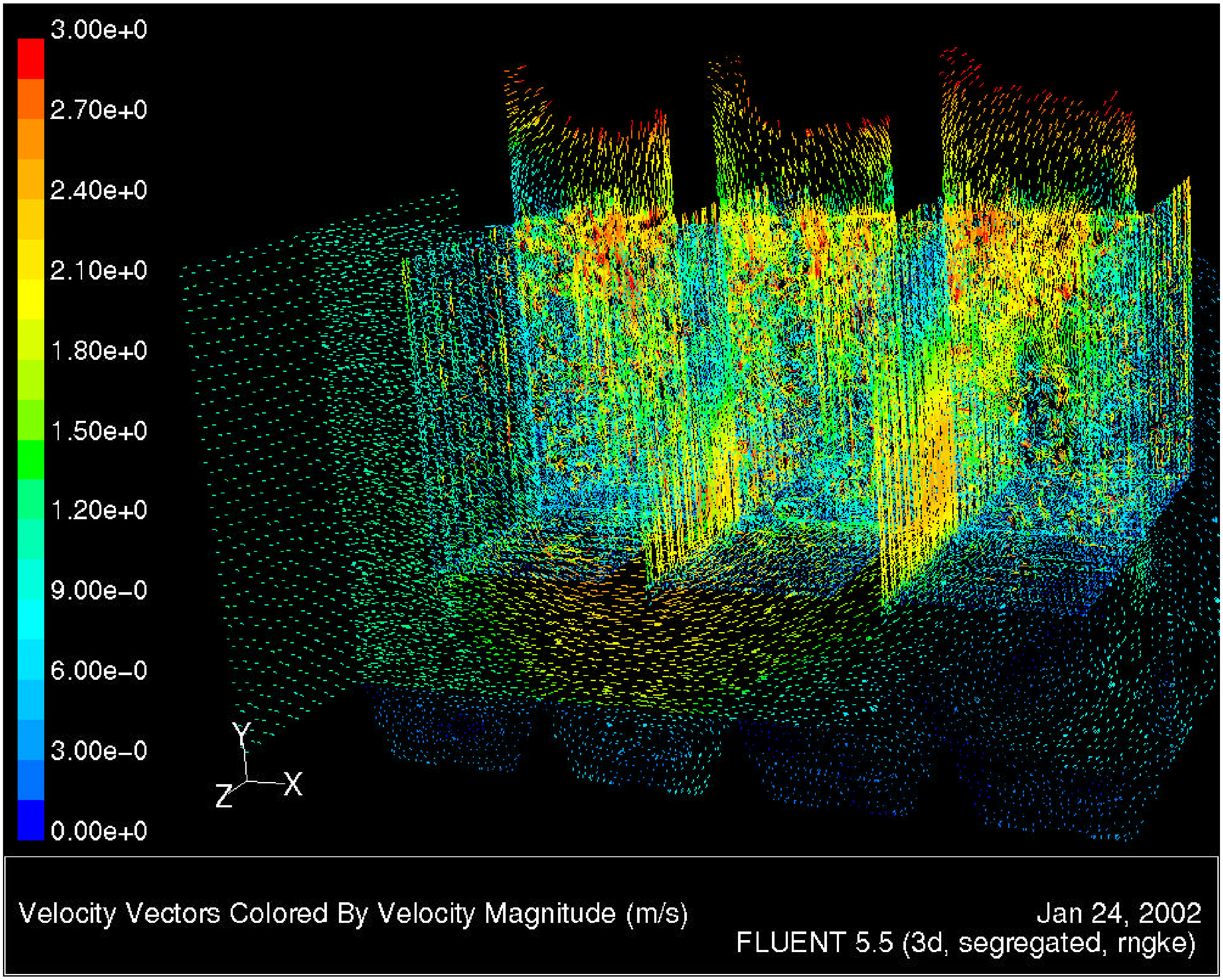
Photograph of Pilot Unit at Big Stone

APPENDIX C – GRAPHICAL RESULTS OF FLOW MODELING

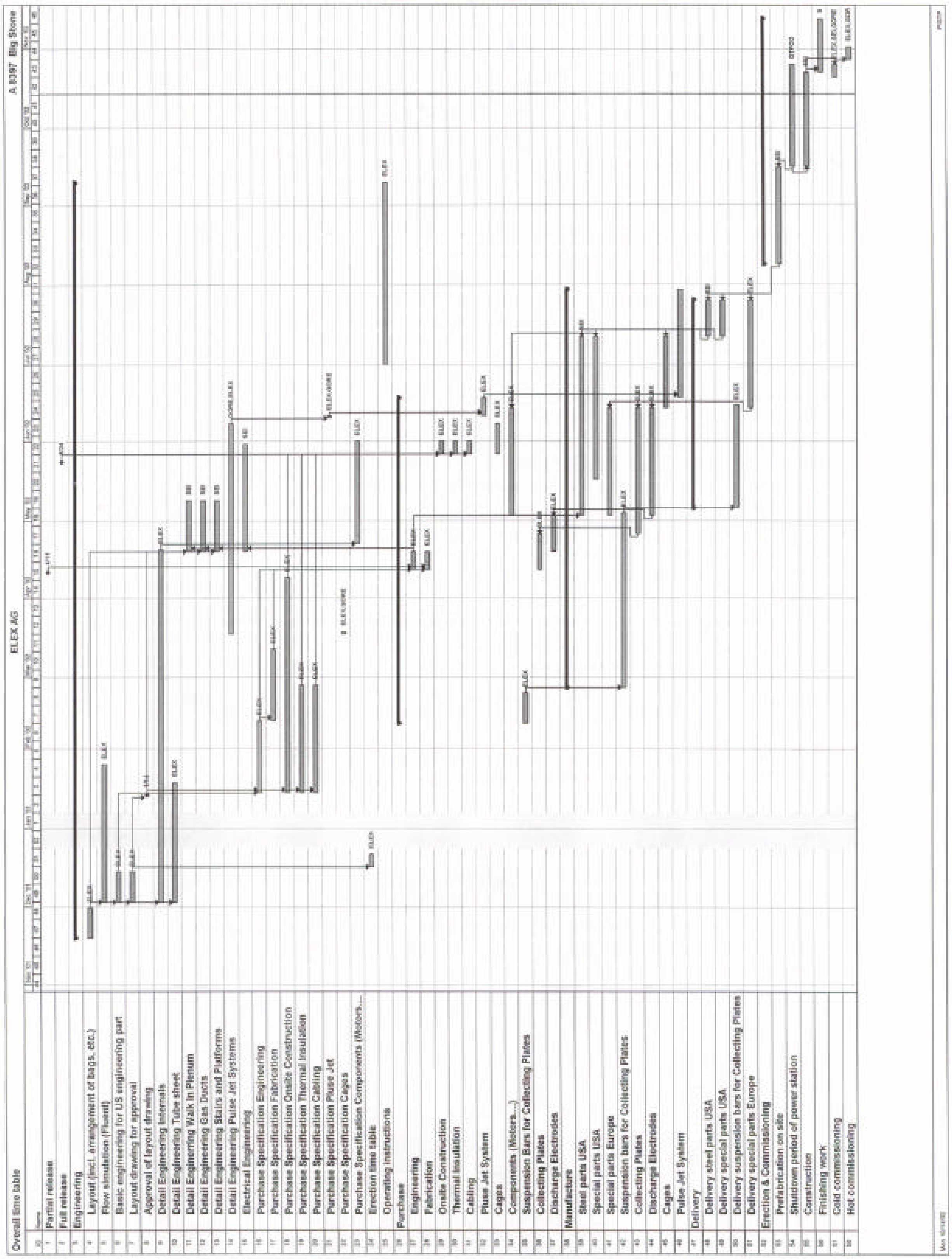
AHPC without internal baffles



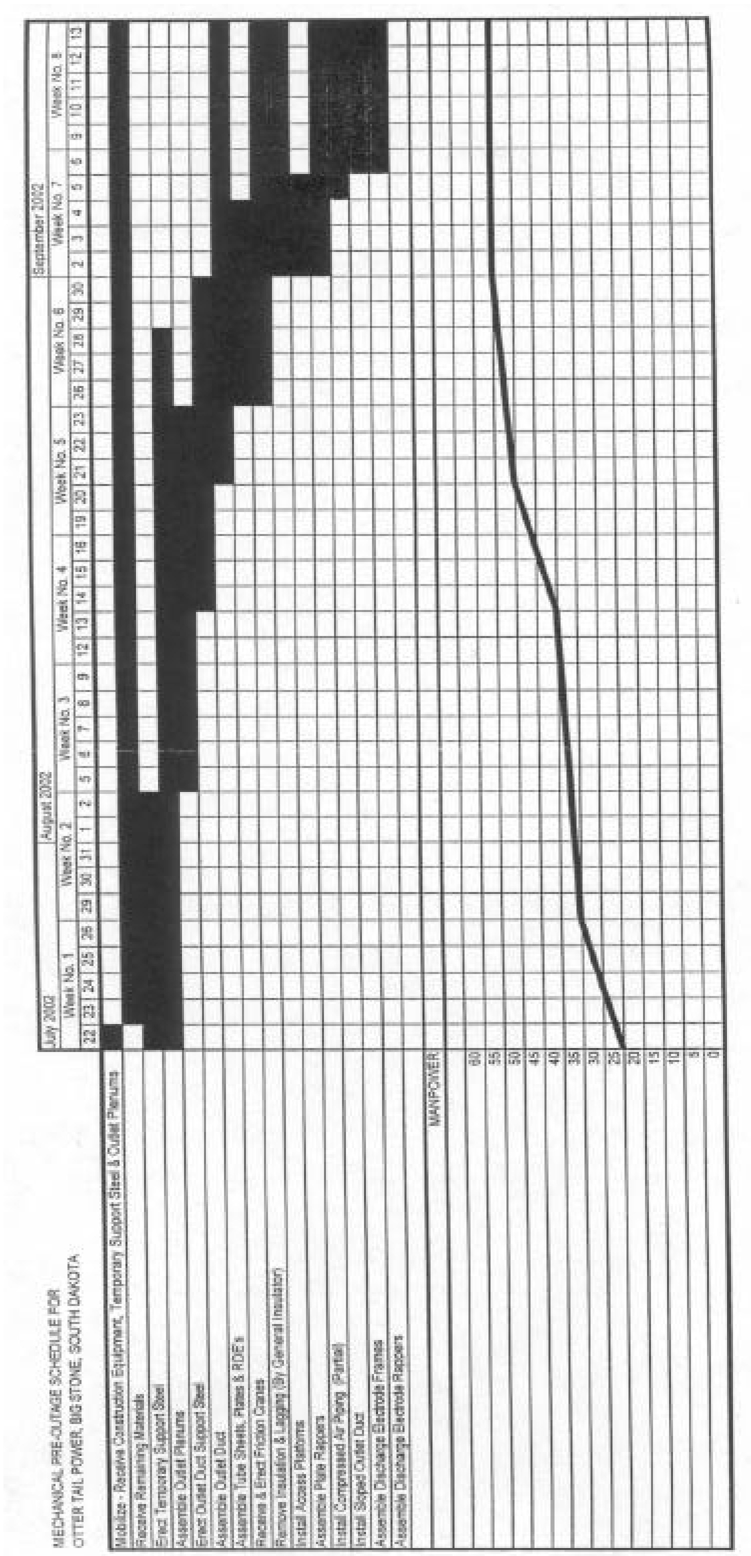
AHPC with internal baffles and rapping devices



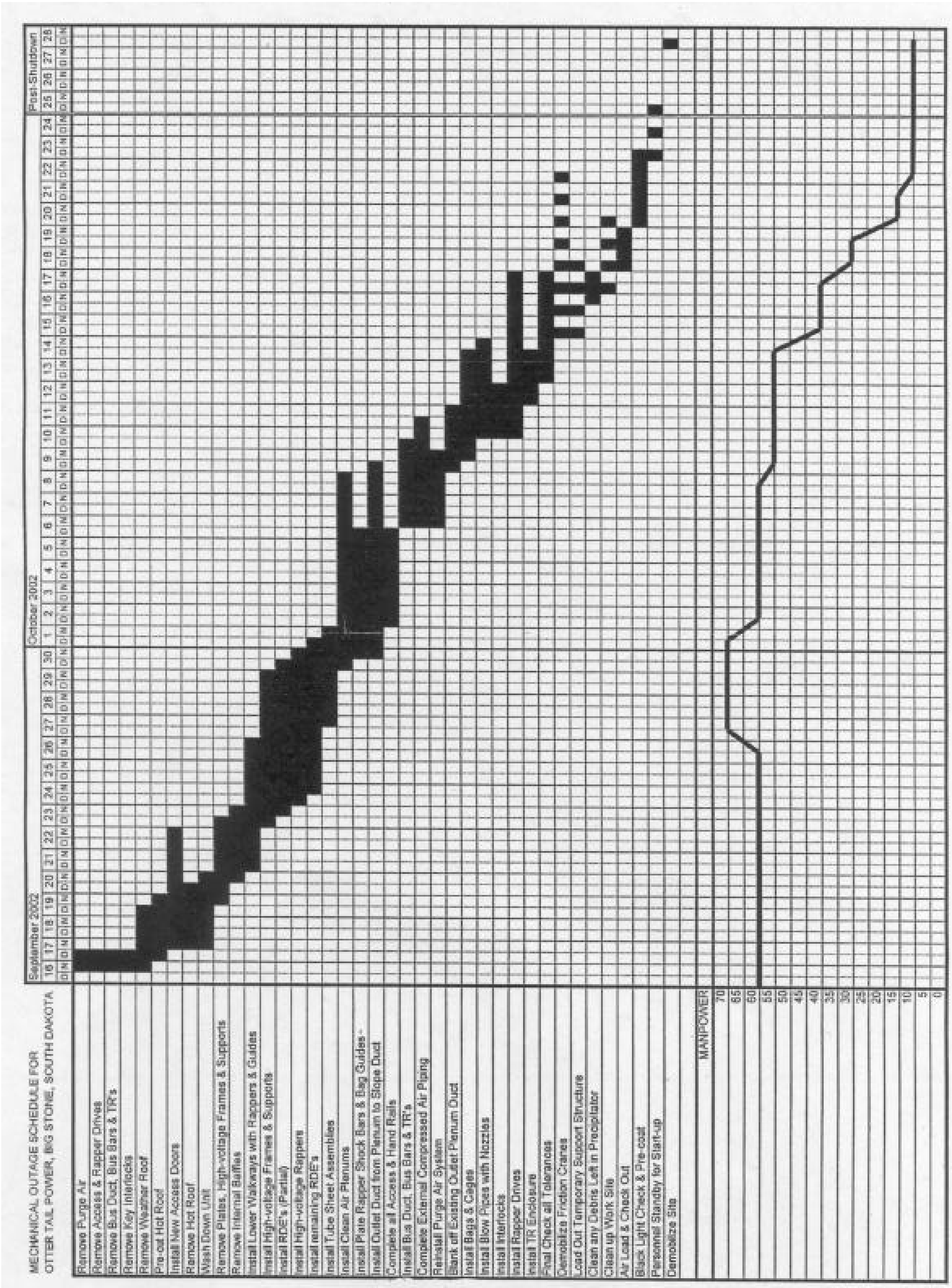
APPENDIX D – OVERALL SCHEDULE



APPENDIX E – PRE-OUTAGE SCHEDULE



APPENDIX F – MECHANICAL OUTAGE & POST SHUTDOWN SCHEDULE



APPENDIX G – COMMISSIONING SCHEDULE